NO. 1

THE GOVERNMENT OF THE KINGDOM OF THAILAND

FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN

SUPPORTING REPORT

1. PLANNING CONDITION
2. HYDROLOGY
3. TELECOMMUNICATION
4. DATA MANAGEMENT
5. IMPLEMENTATION SCHEDULE AND COST ESTIMATES
6. SOCIO-ECONOMY
7. LAND USE
8. RIVER STRUCTURES
9. ORGANIZATION

JUNE 1988

JAPAN INTERNATIONAL COOPERATION AGENCY

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FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN SUPPORTING REPORT JUNE 1988

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LIST OF REPORTS

EXECUTIVE SUMMARY

MAIN REPORT

SUPPORTING REPORT

1. PLANNING CONDITION
2. HYDROLOGY
3. TELECOMMUNICATION
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5. IMPLEMENTATION SCHEDULE AND COST ESTIMATES
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ACRONYMS AND ABBREVIATIONS

ABBREVIATION OF ORGANIZATIONS

AIT	:	Asian Institute of Technology
BMA	:	Bangkok Metropolitan Administration
CAT	:	Communication Authority of Thailand
DDS	:	Department of Drainage and Sewerage, BMA
DOH	:	Department of Highways
DPW	:	Department of Public Works
DTEC	:	Department of Technical and Economic Cooperation
EGAT	:	Electricity Generating Authority of Thailand
HD	:	Harbour Department
IEC	:	Irrigation Engineering Center, RID
LAD	:	Local Administration Department
MD	:	Meteorological Department
NEA	:	National Energy Administration
NEB	:	National Environment Board
NESDB	:	National Economic and Social Development Board
NSO	:	National Statistical Office
PAT	:	Port Authority of Thailand
PTD	:	Post and Telegraph Department
RID	:	Royal Irrigation Department
SRT	:	State Railway of Thailand
TOT	:	Telecommunication Organization of Thailand
FFC	:	Flood Forecasting Center
JICA	:	Japan International Cooperation Agency

ABBREVIATIONS OF MEASUREMENT

Length

mm	:	millimeter(s)
m	:	meter(s)
km	:	kilometer(s)

Area

ha	:	hectare(s)
km^2	:	square kilometer(s)
rai	:	0.16 ha
taran war	:	4 square meters

Volume

m^3	:	cubic meter(s)
MCM	:	million cubic meter(s)

Time

s, sec	:	second(s)
h, hr	:	hour(s)

Other Measurements

HWL	:	High Water Level
MSL	:	Mean Sea Level
°	:	degree
'	:	minute
"	:	second
%	:	percent
°C	:	degree centigrade
m^3/s	:	cubic meter per second
KB	:	kilobyte
MB	:	megabyte
RAD	:	radian
bps	:	bit per second
BPI	:	bit per inch
AH	:	Ampere Hour

ABBREVIATION OF TELECOMMUNICATION AND COMPUTER TERMS

FM : Frequency Modulation
HF : High Frequency
SSB : Single-Side Band
VHF : Very High Frequency
UHF : Ultra-High Frequency
KHz : kilohertz
MHz : megahertz = 10^3 KHz
GHz : gigahertz = 10^3 MHz
CCU : Communication Control Unit
CPU : Central Processing Unit
MPU : Main Processing Unit
MONITOR: Remote Terminal Monitor
FAX : Facsimile
TEL : Telephone
BPPI : Bright PPI Display
SV/RC : Radar Supervisory/Remote Control Equipment
T/R : Transmitter/Receiver
SIG : Signal Processor
MUX : Multiplex Terminal Equipment
TSE : Telemetering Supervisory Equipment
MT : Magnetic Tape
MD : Magnetic Disk
LP : Line Printer
UPS : Uninterrupted Power Supply
AC : Alternating Current
UNIVAC : Universal Automatic Computer
PPI : Plan Position Indicator

OTHER ABBREVIATIONS/ACRONYMS

GDP : Gross Domestic Product
GNP : Gross National Product
GRP : Gross Regional Product
GPP : Gross Provincial Product
R/O : Regional Office
O&M : Operation and Maintenance

INTELSAT : International Communications Satellite Consortium

1. PLANNING CONDITION

SUPPORTING REPORT
ON
PLANNING CONDITION

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1. SUPPORTING REPORT ON PLANNING CONDITION

1. General

The flood forecasting system in the Chao Phraya River Basin aims to mitigate flood damage by controlling flood at the selected target area through the effective operation of river structures, execution of flood fighting works, and so on. For this purpose, the future flood discharge and water stage at the target area are required to be predicted precisely at the flood prediction time, and the flood prediction results have to be disseminated to the agencies responsible for the operation of flood control structures or the execution of flood fighting works.

This sector of the supporting report presents the existing conditions related to the flood forecasting system, and also the study results on the general conditions for the establishment of the flood forecasting system such as the selection of the target area, the required flood prediction time, the agencies to disseminate the flood prediction, and others.

2. Existing Conditions Related to the Flood Forecasting System

2.1 Inundation and Flood Damage

The inundation areas in the whole Chao Phraya River Basin are shown in Fig. 1-1. The major flood damages along the Chao Phraya River are caused by the flood discharge from the river and its main tributaries during the rainy reason. Flood damage in certain areas is caused by local heavy rainfall inundation.

The collected data indicate that flood inundation occurred both in the upper and the lower reaches from Nakhon Sawan. In the upper reaches, flood inundation can be seen in the following areas; while, flood inundation in the lower reaches, which is further discussed hereafter, is widely seen along the Chao Phraya River, especially in the area near Ayutthaya.

(1) Wang River Basin: The area along the Wang River near the confluence with the Ping River

(2) Yom River Basin: The lower reaches of the Yom River from Sukhotai to the confluence with the Nan River

(3) Nan River Basin: The area along several tributaries of the Nan River

The number of residents that received aid from the rescue fund for flood damage of the Social Welfare Department for the period from 1976 to 1985 and the damaged irrigation area are presented in Tables 1-1 and 1-2, respectively. According to these tables, the number of residents and the damaged area in the upper reaches from Nakhon Sawan amount to 401,000 people and 33,000 ha, while those in the lower reaches are 1,542,000 people and 171,000 ha, respectively. It is presumed that flood damage is more serious in the lower reaches from Nakhon Sawan; hence, flood damage mitigation in the lower reaches is emphasized in this flood forecasting system.

Flooding Condition in the Lower Reaches from Nakhon Sawan

Among the recently recorded floods, those that occurred in 1975, 1978, 1980 and 1983 had inflicted severe damage to the downstream areas. For the purpose of identifying the target area for this flood forecasting system, the flooding conditions in the lower reaches from Nakhon Sawan are herein further described.

(1) 1975 Flood

The flood in 1975 that had the discharge of 4,400 m3/s and 3,900 m3/s at the water gauging stations of Nakhon Sawan and Chai Nat, respectively, overtopped at several points along the river course between Chai Nat and Ayutthaya, as shown in Fig. 1-2. Although the inundation area was not clarified, the flood brought about inundation to the agricultural land on the right bank side of the lower reaches from Ang Thong along Chao Phraya River, and also to the areas in and around the cities of Ang Thong and Ayutthaya. Paddy, livestock and some facilities were damaged, and in Bangkok Metropolis, flood damage amounted to 1,100 million bahts. (Refer to Table 1-3.)

(2) 1978 Flood

The flood discharges observed at Nakhon Sawan and Chai Nat stations were 3,500 m^3/s and 3,700 m^3/s, respectively, while that at Ang Thong Station in the lower reaches of Chai Nat marked 2,800 m^3/s. From these observed data, it is believed that flood discharge overtopped the bank between Chai Nat and Ang Thong, as verified from the inundation map in Fig. 1-3(1/3) and the overtopping location map in Fig. 1-2.

The flood damage data show that inundation occurred in the agricultural area between Sing Buri and Ayutthaya and also in the Ayutthaya urban area. The maximum flood discharge in the basin of Pasak River, a tributary of the Chao Phraya River, was 3,200 m^3/s, which was almost equal to that in the Chao Phraya River Basin. Flood damage to the agricultural area along the Pasak River was reported, and flood damage caused by local rainfall has also been detected, especially in the area along the Chai Nat-Pasak Irrigation Canal and Lop Buri River. In Bangkok Metropolis, flood damage has been reported as that of an average flood.

(3) 1980 Flood

In this flood, damage occurred in several places in the lower reaches due to the inundation by local rainfall and the flood discharge from the main channel which had inflicted a more severe damage. The flood discharge of 4,400 m3/s and 3,700 m3/s observed at Nakhon Sawan and Chai Nat, respectively, inundated both sides of the Chao Phraya river course between Chai Nat and Ayutthaya, inflicting tremendous damage to the agricultural area (refer to Fig. 1-3(2/3). Also, several cities along the main river course such as Nakhon Sawan, Chai Nat, Sing Buri, Ang Thong and Ayutthaya were exposed to the flooding water from the river channel. In the Bangkok Metropolis, flood damage was reported at 450 million bahts.

(4) 1983 Flood

The peak discharge of 2,300 m^3/s in the upper reaches from Nakhon Sawan during the flood in 1983 was not so large compared with the previous three floods. However, in the lower reaches the peak discharge surged to 3,300 m^3/s at Chai Nat and 3,700 m^3/s at Ang Thong. The flood which overtopped at several points also brought inundation to the area along the river course between Chai Nat and Ayutthaya, as well as other cities such as Ang Thong, Lop Buri, and Ayutthaya.

In Bangkok Metropolis, flood damage during the year amounted to 6,500 million bahts, due to multiple causes such as flood discharge from the Chao Phraya River, high tide, local rainfall and inflow discharge from the outer area.

In Ang Thong City, about 6,100 houses and 200 office buildings, temples and schools were damaged, amounting to about 6 million bahts. Inundation caused by local rainfall also occurred in the lower reaches near Bangkok Metropolis, as shown in Fig. 1-3(3/3).

The road network along the Chao Phraya River was also reported to have been habitually damaged in the lower reaches, but not in the upper reaches, as shown in Fig. 1-4. The railway has not suffered from any flood for the past 10 years.

2.2 Related Ongoing Projects

Studies on several projects have been previously undertaken. The following projects in the Chao Phraya River Basin are specifically related to this Study.

Flood Control Projects

In the field of flood control, most projects in the area were proposed for flood damage mitigation in Bangkok and in adjacent areas. These projects are the following:

(1) Bangkok Flood Control and Drainage Project (City Core)

This project aims to provide a flood control system consisting of embankments, drainage canal with pumps, control gate, etc., for the target area which covers 89 km2 in the city core of Bangkok Metropolis. The feasibility study for this project was undertaken in 1984 by the Department of Drainage and Sewerage (DDS) of BMA, and the study shows a financial investment of about 3,000 million bahts in the constant price of 1983, with the IRR expected to be more than 30%. MBA is planning to proceed with the project.

(2) Flood Protection and Drainage Project in Eastern Suburban Bangkok

As in the flood control and drainage project in the city core area, this project aims to provide a flood control system for Eastern Suburban Bangkok. For this purpose, several studies have been conducted such as the Preliminary Study in 1984 that covered the area of 501 km2, and the Master Plan Study in 1985 and Feasibility Study in 1986 that covered the area of 260 km2.

For the implementation of the project in the F/S study area, the required cost was estimated at 2,700 million bahts in the price of 1985 and the IRR was 20%.

(3) Greenbelt Project

This project was planned to prevent the inflow of flood discharge to Bangkok from the adjoining paddy fields in the eastern and the northern areas, and to drain the discharge into the Gulf of Thailand. The master plan for this project was worked out in 1981 after the serious flooding in 1980, and part of the project involved the construction in 1984 of embankments of about 76 km in length, as well as gates, as the urgent flood control measures formulated in 1983.

(4) Urgent Flood Control Measures Against the 1983 Flood

Due to the severe damage caused by the 1983 flood, flood protection works for the Bangkok Metropolis has been urgently executed by the construction of embankment, improvement of drainage canal, provision of drainage pump, and so on. This project was completed in 1984 at the cost of 1,000 million bahts.

(5) Samut Prakan Seawall Project (Study in 1984)

The purpose of this project is to prevent inflow from the outer area to the coastal plain of Samut Prakan by providing a dike along the Chao Phraya River, the Gulf of Thailand, and the Greenbelt area.

(6) Alternative Flood Control Scheme Proposed by AIT (Study in 1985)

This project aims to lower the water level and to shorten the period of flooding of the Chao Phraya River through the construction of a bypass channel eastward of the Chao Phraya River.

(7) Flood Protection of Bangkok, Chao Phraya 2 (F/S in 1986)

The purpose of this project is to protect Bangkok Metropolis and its vicinity against peak flows of the Chao Phraya River, tidal influence, etc. The construction of structures was proposed, namely, (1) one diversion channel with the flow capacity of 2,000 m^3/s, (2) control structure for the diversion of flood discharge or sea barrier structure, and (3) drainage pump with the drainage capacity of 1,600 m^3/s. The total construction cost was estimated at 19,500 million bahts, while the economic internal rate of return as direct benefits was expected to be 30%.

(8) Flood Control Project for Flood Protection and Drainage Operation in Bangkok and Its Vicinity (Under Study)

The purpose of this project is to provide a flood control center, together with a telemetering and monotoring system, for the smooth operation of flood control facilities.

Aside from the above, project offices of RID are constructing embankments along the Chao Phraya River to protect the agricultural area from flood.

Data Management System

In the field of data management system, the following projects are significant.

(1) Irrigation Engineering Center Project (Under Study)

The purpose of this project is to supplement the present water management system established by RID in 1982 and to provide facilities for data monitoring and a management system for the smooth utilization of water resources in the basin. For the purpose, RID is planning to introduce new data management facilities.

(2) Water Management System and Monitoring Project in the Chao Phraya River Basin (Under Study)

The study aims to formulate a master plan for the efficient and proper management of water resources by evaluating potential water resources and dependable water availability for agricultural development. It also aims to rationalize water use among existing projects in the same basin with consideration on the scope of future agricultural development in the region.

2.3 Flood Forecasting Practice

There are two agencies conducting flood forecasting in the Chao Phraya River basin, namely, MD and EGAT.

MD

MD has been studying the appropriate flood prediction model for three basins, namely, the upper reaches of Nan River Basin, the upper reaches of Pasak River Basin and the Prachan Buri River Basin. The flood prediction results for the upper reaches of Pasak River Basin which shows well coincidence between the predicted value and the observed one have been published recently in the weekly weather report, including weather condition forecast for the succeeding week.

EGAT

EGAT has been conducting flood forecasting on the whole Chao Phraya River Basin since 1979 for use in dam operation. Flood information has been transmitted to RID and other concerned agencies in the form of weekly reports to provide information for their flood fighting activities.

In the flood forecasting system of EGAT, future water stage is predicted seven days in advance at the Memorial Bridge Point in Bangkok, together with the inflow volume to the Bhumibol and the Sirikit dams and the discharge at Nakhon Sawan Station. The flood prediction model used in this flood forecasting system is based on that developed by AIT in 1978.

3. Study on Conditions for the Establishment of the Flood Forecasting System

3.1 Selection of Target Area and Flood Prediction Point

3.1.1 Target Area

The target area is defined as the area where a flood forecasting system is required to help mitigate flood damage as much as possible through flood fighting works. Since the flood damage condition in the lower reaches of Nakhon Sawan has been more serious than in the upper reaches, as mentioned in the preceding section, the objective area for the selection of the target area was firstly narrowed down to the lower reaches from Nakhon Sawan, and following conditions were taken account:

(1) Areas suffering from damage caused by flood from the Chao Phraya River and its main tributaries, since the damage is generally more serious than that caused by local rainfall inundation.

(2) Urbanized and populated areas where serious damage by inundation due to flood discharge from the Chao Phraya River is highly expected. These include agricultural areas that are habitually suffering from flood damage.

Judging from the previous flood inundation map and the flood damage information gathered from interviews with provincial offices, the following areas were eventually selected as target areas (refer to Fig. 1-5).

(1) Bangkok Metropolis and urban areas in Nakhon Sawan, Chai Nat, Sing Buri, Lop Buri, Ang Thong and Ayutthaya; and

(2) Agricultural area along the Chao Phraya River between Ang Thong and Ayutthaya, and along the Pasak River between Ayutthaya and the Rama VI Dam.

Among these areas, top priority for the establishment of a flood forecasting system is given to Bangkok Metropolis in view of the following reasons. The next priority is given equally to all the other target areas, so that the flood forecasting system can be established at the same time as much as possible.

(1) Bangkok Metropolis with a large population of about 30% of the whole basin population (Refer to Table 1-4.) is literally the core of the nation's various activities. It is also very vulnerable to flood damage, as shown in Table 1-3.

(2) Flood damage potential in Bangkok Metropolis is increased as the river embankment along the Chao Phraya river course is developed, because flood discharge tends to increase more than ever; and,

(3) Flood prevention effects can be maximized in this area through the prediction of the water stage of the Chao Phraya River.

3.1.2 Flood Prediction Point

At several points, flood discharges and/or water stages will be predicted to enable carrying out of the necessary actions for flood damage prevention in the target area. Thus, the flood prediction points were selected where the flooding condition on the target area can be well defined.

In principle, one flood prediction point has been selected for each target area. However, three (3) flood prediction points were selected for the Bangkok Metropolis, since this target area covers a wide stretch influenced by the tidal fluctuation along the Chao Phraya River. The maximum water stage along the wide stretch may occur at different times with different heights depending upon the points observed.

The following points at which the water stage has been observed by existing gauging stations were selected. (Refer to Fig. 2-5.)

(1)	Bangkok Metropolis	:	Bangkok Memorial Bridge, RID Samsen, and Pakred Station
(2)	Ayutthaya	:	Confluence point of Chao Phraya River and Pasak River
(3)	Agricultural area in the upper reaches from Ayutthaya along the Chao Phraya River and Ang Thong	:	Ang Thong Station
(4)	Agricultural area along the Pasak River near Ayutthaya	:	Rama VI Barrage
(5)	Ang Thong	:	Ang Thong Station
(6)	Sing Buri	:	Sing Buri Station
(7)	Lop Buri	:	Lop Buri Station
(8)	Chai Nat	:	Chai Nat Station
(9)	Nakhon Sawan	:	Nakhon Sawan Station

3.2 Flood Prediction Time

In this study, flood prediction time is defined as the period from which hydrological data is observed up to the time the flood discharge is predicted (refer to Fig. 1-6.). The flood prediction time for the flood forecasting system is studied in two cases according to objective, as follows:

(1) Short Term Flood Prediction Time

A shorter flood prediction time is considered for urgent flood protection works in the target area.

(2) Long Term Flood Prediction Time

A longer flood prediction time is applied in case of integrated flood protection works to effectively operate the water control river structures in the basin.

3.2.1 Short Term Flood Prediction Time

<u>Activities During Flood Prediction Time</u>

During the flood predictions, the following items of work are performed mainly after hydrological observation:

(1) Data collecting, processing, filing and calculation for flood prediction.

(2) Dissemination of flood prediction results to agencies concerned.

(3) Deliberation on the necessary countermeasures.

(4) Dissemination of the necessary countermeasures to agencies involved.

(5) Execution of the necessary countermeasures.

Among the above items of work, the necessary time for execution of items (1) and (2) will change according to the type and kind of system employed, while that of items (3), (4) and (5) which belong to the works for the flood warning and flood fighting is basically unchangeable even in the introduction of a new system. In case all these works are performed by one agency, item (2) is not involved in the flood prediction time. In this connection, the short term flood prediction time is studied in two cases, Step 1 and Step 2, on the basis of the necessary flood prediction time presumed under the present activities of the agencies concerned.

Necessary Time Presumed Under the Present Activities

To estimate the necessary flood prediction time, the actual procedures taken by the agencies concerned were studied. Among the agencies involved in flood forecasting and flood protection works, the following undertake the above items of work according to the time allotted by them for the purpose.

(1) RID

RID executes most of the aforementioned items of work in the Chao Phraya River Basin, excluding the prediction of flood discharge. Although the time spent in these works can hardly be fixed, the minimum time required for each activity has been presumed through the interview survey as follows, with one day assumed as 10 hours from 8:00 a.m. to 6:00 p.m.

(a)	Data Collection, Processing and Filing	:	2.0 days
(b)	Dissemination of Flood Prediction Results to Agencies Concerned	:	0.0
(c)	Deliberation on the Necessary Countermeasures	:	0.3 days
(d)	Dissemination of the Instructions on the Necessary Countermeasures to Internal Agencies of RID	:	0.2 days
(e)	Execution of the Necessary Countermeasures	:	2.0 days
	Total	:	4.5 days

The countermeasures taken by RID include putting sand bags on the river banks, operating regulators and choking up of open channels without regulator.

(2) BMA

BMA conducts most of the aforementioned activities for the Bangkok Metropolis, excluding the prediction of the flood discharge. Since the area covered by BMA is not so large compared with that of RID, all of the works can be performed in a relatively shorter time of one or two days, although the necessary time for each activity is not clear.

The countermeasures taken by BMA include operating drainage pumps and regulators on the drainage channel and putting sand bags on the banks of the Chao Phraya River.

(3) EGAT

EGAT's participation in flood forecasting is through the processing and filing of hydrological data, calculating flood prediction and disseminating results to the agencies concerned. Since EGAT obtains some of the hydrological data from RID, the necessary time for data collection is related to that of RID. Therefore, 2.5 days are required for data collection and transmission, processing and filing, including the 0.5 day for flood prediction. The dissemination of flood prediction results to agencies concerned including report preparation is 1.5 days, so that the total time spent for the above activities is 4.0 days.

Judging from the activities of the above agencies, those of RID seem to be more adaptable to the estimation of the necessary prediction time, even if flood discharge prediction and its dissemination to the agencies concerned is not included. The necessary flood prediction time is estimated on the following assumptions:

(1) The necessary time for calculation of the flood prediction is 0.5 days, judging from the activities of EGAT; and

(2) The necessary time for the dissemination of flood prediction results to agencies concerned is 0.5 days, which is estimated in terms of delivery of the results manually, because the TOT line is not expected to be available during flood time.

Based on the above assumptions, the necessary flood prediction time presumed under the present activities is 5.5 days, summarized as follows and shown in detail in Table 1-5.

(1)	Data Collection, Processing, Filing and Calculation of Flood Prediction	:	2.5 days
(2)	Dissemination of Flood Prediction Results to Agencies Concerned	:	0.5 day
(3)	Deliberation on the Necessary Countermeasures	:	0.3 day
(4)	Dissemination of the Instructions on Countermeasures	:	0.2 day
(5)	Execution of the Countermeasures	:	2.0 days
	Total	:	5.5 days

Minimum Flood Prediction Time Required For Step 1 System

The Step 1 Flood Forecasting System is formulated on the basis of the existing facilities. Therefore, the minimum flood prediction time required for items (1) and (2) will not be shortened remarkably in the Step 1 system, as explained below.

(1) Data Collection, Processing, Filing and Calculation of Flood Prediction

The necessary time for data collection from some stations can be shortened through the installation of additional telecommunication facilities. However, the present data collection process for the other stations is applied to Step 1, so that the necessary time for data collection cannot be remarkably shortened. Also, the necessary time for manual operation of data processing, filing and calculation of flood prediction is not expected to be shortened.

(2) Dissemination of Flood Prediction Results to Agencies Concerned

The necessary time of this work, which is currently presumed at 0.5 day including preparation of the documents, will be shortened through the introduction of telecommunication facilities for dissemination. Here, the time of 0.3 day necessary for preparation of document and dissemination by the telecommunication facilities is applied to the estimation of flood prediction time.

Correspondingly, the minimum flood prediction time required for the Step 1 system is estimated as follows:

(1)	Data Collection, Processing, Filing and Calculation of Flood Prediction	:	2.5 days
(2)	Dissemination of Flood Prediction Results to Agencies Concerned	:	0.3 day
(3)	Deliberation on the Necessary Countermeasures	:	0.3 day
(4)	Dissemination of the Instructions on Countermeasures	:	0.2 day
(5)	Execution of the Countermeasures	:	2.0 days
	Total	:	5.3 days

Minimum Flood Prediction Time Required For Step 2 System

The Step 2 flood forecasting system is formulated on the basis of updated facilities, i.e., online telemetering system. It is, therefore, expected that the minimum flood prediction time required is shortened remarkably for items (1) and (2), as follows:

(1) Data Collection, Processing, Filing and Calculation of Flood Prediction

The necessary time for collecting, processing, filing and calculating flood prediction, which is presently estimated at 2.5 days, can be shortened to 0.2 days with the introduction of the online telemetering system. This system will enable real-time data collection, processing, filing and calculation of flood prediction. Only a supplemental operation manual for data check, data input, etc., may be needed from time to time.

(2) Dissemination of Flood Prediction to Agencies Concerned

Since the flood prediction results are easily disseminated by the use of a facsimile equipment, the necessary time for this work may be 0.2 days.

From the above consideration, the necessary flood prediction time for the Step 2 system is estimated at 2.9 days, as follows:

(1)	Data Collection, Processing, Filing and Calculation of Flood Prediction	: 0.2 day
(2)	Dissemination of Flood Prediction Results to Agencies Concerned	: 0.2 day
(3)	Deliberation on the Necessary Countermeasures	: 0.3 day
(4)	Dissemination of the Instructions on Countermeasures	: 0.2 day

(5) Execution of the Countermeasures : 2.0 days

Total : 2.9 days

Comparison of Flood Prediction Time Between Step 1 and Step 2

Generally, the reliability of prediction results tends to decrease in proportion to the length of flood prediction time, although the reliability is hardly evaluated in quantitative terms. The minimum flood prediction time required for the Step 2 system can be shortened to 2.9 days from the 5.3 days needed for the Step 1 system which is almost double of that for Step 2. In the case of the Step 2 system, flood fighting works can be executed on the basis of the more precisely predicted data, so that more appropriate measures can be taken.

3.2.2 Long Term Flood Prediction Time

Flood prediction is based on the observed hydrological data, sometimes using additionally the estimated future rainfall to make the prediction period longer. A longer term of flood prediction enables a more effective operation of the flood control structures because flood protection activities can be undertaken much in advance of the flood occurrence. However, this also involves a question of prediction reliability, i.e., accuracy becomes lower in proportion to the length of prediction time.

Long term flood prediction is also made up to the allowable extent by using only the observed rainfall data to maintain accuracy. The period of prediction may correspond to the flood lag time consisting of the concentration of intensive daily rainfall and traveling time of the peak flood discharge to the target area.

The flood runoff of Chao Phraya River is subject to the characteristics of that of the Ping River where peak discharges of intensive daily rainfall abruptly appear and are directly propagated to Nakhon Sawan. Hence, it may be impossible to predict floods covering a long period with an allowable accuracy by means of estimating the future rainfall.

3.3 Time Interval to Update Flood Prediction Results

Flood prediction results, especially short term flood prediction results which are immediately disseminated to the agencies concerned in flood fighting works, shall be updated by the collection of newly observed data to cope with the abrupt change in flood water stage. Thus, it is necessary to set the time interval for the updating of flood prediction results, in consideration of the flooding condition in the target area and the possible time interval for data collection.

Time Interval Based on Flood Condition

Flood condition in the target area differs between the upper and the lower reaches from Bang Sai. The time interval for updating of flood prediction results can be set as follows:

(1) Upper Reaches from Bang Sai

The flood water stage in this stretch continuously rises for one week or more when there is heavy rainfall in the upper basin. According to the observed data of the 1978, 1980 and 1983 floods, in case of the flood discharge of more than 2,000 $m3/s$ the maximum daily change of the flood water stage at Nakhon Sawan, Chai Nat and Ang Thong is between 0.05 m and 0.47 m, as shown in Table 1-6. Although it is very difficult to define the abrupt change with the definitive flood water stage rise, this should be set from the aspect of flood fighting works.

In the foregoing case, the water stage of 15 cm, which nearly corresponds to the thickness of one layer of sandbag or concrete block piled up on the bank to prevent overtopping water, is applied to the abrupt change, assuming that the water stage of 15 cm is within the possible extent to be coped with through one time flood fighting works. In this connection, the time interval to update the flood prediction results will come to 6 hours, i.e., four times a day, which is derived by dividing the maximum daily water stage change of 47 cm by the said 15 cm.

(2) Lower Reaches from Bang Sai

Since the lower reaches from Bang Sai is affected by tidal fluctuation, the change of water stage in the stretch sometimes comes to 10 cm or more even on the hourly basis. However, since the peak tidal stage in this stretch emerges periodically, it is possible to know the time of occurrence of the peak water stage in advance. Moreover, the peak water stage can be predicted by using the newly observed data, so that appropriate flood fighting works can be taken to cope with the predicted water stage. For the execution of flood fighting works, it is sufficient to update the flood prediction results in accordance with the time interval of the peak tidal stage of approx. 10 to 14 hours.

<u>Possible Time Interval For Data Collection</u>

It is desirable to collect the data within the same time frame as the updating of flood prediction results. However, the possible time interval for data collection depends on the method of data collection which differs between the Step 1 and the Step 2 systems.

In the Step 1 system, it is proposed that data collection is performed once a day by manual operation on the basis of the currently used system, while it is based on the telemetering system in Step 2 where the data can be collected on real time with no time interval. In this connection, the possible time interval for data collection is one day in the Step 1 system, while any time interval can be applied in the Step 2 system.

Under the above situations, the time intervals to update the flood prediction results are set at one day for the Step 1 system, and six hours for the upper reaches from Bang Sai and ten hours for the lower reaches from Bang Sai for the Step 2 system. To uniformly operate the flood forecasting system for all the target areas, it is recommended to adopt the six hours time interval for both the upper reaches and the lower reaches for convenience.

3.4 Agencies to Disseminate the Flood Prediction Results

One of the main purposes of the flood forecasting system is to provide the appropriate flood information to serve as basic data for the execution of the urgent flood protection works at the target area and for the operation of the water control facilities to regulate the flood discharge. Therefore, it is necessary to discuss the flood information consisting of the observed hydrological data and the flood prediction result to the agencies responsible for the execution of flood protection works and the operation of water control structures.

Agencies Responsible for Flood Protection Works

The target area includes the major urban area along the river course, namely, Bangkok, Ayutthaya, Ang Thong, Sing Buri, Lop Buri, Chai Nat and Nakhon Sawan, and also the agricultural area in the upper reaches from Ayutthaya along the Chao Phraya River and along the Pasak River. The agencies responsible for flood protection works at these areas were identified from their functions, as follows:

Bangkok Metropolis	:	Bangkok Metropolitan Administration
Ayutthaya, Ang Thong, Sing Buri, Lop Buri, Chai Nat, Nakhon Sawan	:	Local Administration Department (LAD) of MI and Provincial Office

Agricultural Area : RID

As for the protection works at Ayutthaya, Ang Thong, etc., the instructions for protection works are basically given by LAD of MI to each provincial office.

Agencies Responsible for Operation of Water Control Structures

There exist many water control structures in the Chao Phraya River Basin and those involved in flood control are the Bhumibol Dam, the Sirikit Dam, the Chai Nat Dam, the Manorom Regulator, the Maharaj Regulator, the Phonlatep Regulator, the Borommathat Regulator and the Rama VI Barrage. The agencies responsible for the operation of these structures are EGAT for the Bhumibol and Sirikit dams, and RID for the Chai Nat Dam, Rama VI Barrage and the other regulators.

Based on the above situations, the agencies to disseminate flood information would be the Bangkok Metropolitan Administration, the Civil Defence Division of MI, and the EGAT. As for the dissemination to the provincial office, the information is expected to be transmitted through the Civil Defence Division by its own communications network.

3.5 Phased Implementation

3.5.1 Necessity of Phased Implementation

Since the Step 1 system is formulated by using the existing facilities to the maximum extent, it may be possible to establish this system in a short period of time. On the other hand, the Step 2 system requires a newly installed hydrological observation network covering the area of 160,000 km2 with the provision of telecommunication network. Consequently, it is expected that the construction work volume is so large that it may be difficult to accomplish the overall work in a short period of time. Therefore, it is essential to set up the appropriate implementation schedule so as to promptly produce the desirable effects of the system in accordance with the progress of construction works. In connection with the Step 2 system, it is proposed that the overall flood forecasting system is divided into several subsystems in accordance with the purpose and area to be covered.

3.5.2 Priority of Each Subsystem

The total system can be divided into several subsystems from the aspects of flood prediction time and target area, as tabulated below:

Item	Purpose
Flood Prediction Time	a. Short term flood prediction
	b. Long term flood prediction
Target Area	a. Bangkok with top priority
	b. The other target areas with next priority

From the above table, higher priority is put on the short term flood prediction, since the prediction results will be effective for use on urgent flood fighting works which is regarded as the primary purpose of the flood forecasting system. Needless to say, flood forecasting for Bangkok as the top priority target area is proposed over those of other target areas and in this connection, it is proposed that the subsystems are arranged according to the following order:

First Priority : Short term flood prediction for Bangkok

Second Priority : Short term flood prediction for the other target areas

Third Priority : Long term flood prediction for Bangkok

Fourth Priority : Long term flood prediction for the other target areas

TABLES

Table 1-1. ALLOCATIONS FROM THE SOCIAL WELFARE RESCUE FUND (1976-1985)

Unit: x 10^3

Basin	Province	Number of Persons	Amount Allocated (Baht)
Upper Reaches from Nakhon Sawan	Chiang Mai	22	697
	Lampang	7	77
	Lamphun	53	226
	Phrea	-	1
	Nan	73	831
	Tak	5	424
	Sukhothai	17	643
	Phitsanulok	125	863
	Uttaradit	7	359
	Kamphaeng Phet	5	172
	Phichit	28	533
	Phetchaboon	59	1,089
	Sub-Total	401	5,915
Lower Reaches from Nakhon Sawan	Nakhon Sawan	143	3,146
	Uthaithani	84	1,303
	Chai Nat	143	966
	Kanchanaburi	52	1,634
	Suphan Buri	41	715
	Sing Buri	229	575
	Lop Buri	21	1,189
	Ang Thong	104	2,613
	Saraburi	10	675
	Ayutthaya	87	1,890
	Nakhon Pathom	1	37
	Nonthaburi	60	1,685
	Pathumthani	23	392
	Samut Sakorn	3	53
	Bangkok	96	963
	Samut Prakarn	7	93
	Rajchaburi	37	2,690
	Sub-Total	1,141	20,619
	Total	1,542	26,534

Source: Dept. of Social Welfare

Table 1-2. FLOOD DAMAGED IRRIGATION AREA

(Unit: ha)

Year	Upper Reaches of Nakhon Sawan (Regions 1, 2 & 3)	Lower Reaches of Nakhon Sawan (Regions 7 & 8)
1975	7,079	25,958
76	1,278	1,080
77	4,644	4,992
78	1,200	21,641
79	8,124	0
80	2,819	28,630
81	4,542	170
82	2,070	744
83	580	87,697
84	160	59
85	162	61
Total	32,658	171,032

Source: RID

Table 1-3. FLOOD DAMAGE CONDITION IN BANGKOK

Flood Year	Area	Investigated Item	Estimated Cost of Damage (in million Baht)	Source of Estimate
1975 Flood	Bangkok	Direct damage, indirect damage and utility losses.	1,100	Water Resources Committee, NESDB
1980 Flood	Central Bangkok Area	Direct damage, indirect damage and flood prevention cost.	450	Burkhard
Normal Flood Between 1975 and 1982	Central Bangkok Area	Damage and losses to households, small and large establishments, institutions, public utilities, road users, tourism sector and environmental conditions.	800	NEDECO
1983 Flood	Greater Bangkok Area	---	6,597	National Statistical Office

Table 1-4. POPULATION DENSITY BY PROVINCE

Item No.	Name of Province	Area of Province (km^2)	Population in 1984 (person)	Population Density ($person/km^2$)
Upper Reaches from Nakhon Sawan				
1	Chiang Mai	20,107	1,252,241	62.3
2	Lampang	12,534	730,057	58.2
3	Lamphun	4,506	392,588	87.1
4	Phrea	6,539	471,101	72.0
5	Nan	11,472	410,484	35.8
6	Tak	16,407	311,767	19.0
7	Sukhothai	6,596	560,219	84.9
8	Phitsanulok	10,816	722,475	66.8
9	Uttaradit	7,839	437,853	55.9
10	Kamphaeng Phet	8,608	628,789	73.0
11	Phichit	4,531	558,236	123.2
	Sub-Total	109,955	6,475,810	58.9
Lower Reaches from Nakhon Sawan				
1	Nakhon Sawan	9,598	1,031,924	107.5
2	Phetchabun	12,668	893,940	70.6
3	Uthai Thani	6,730	280,184	41.6
4	Chai Nat	2,470	332,412	134.6
5	Kanchanaburi	19,483	607,171	31.2
6	Suphan Buri	5,358	751,875	140.3
7	Singburi	822	208,838	253.5
8	Lopburi	6,200	671,823	108.4
9	Angthong	968	466,195	481.6
10	Saraburi	3,576	469,064	131.2
11	Ayutthaya	2,557	637,845	249.5
12	Nakhon Pathom	2,168	596,157	275.0
13	Nonthaburi	622	478,199	768.8
14	Pathom Thani	1,526	366,767	240.3
15	Samut Sakorn	872	301,631	345.9
16	Bangkok	1,565	5,174,682	3,306.5
17	Samut Prakarn	1,004	640,316	637.8
18	Ratchaburi	5,196	675,148	129.9
	Sub-Total	83,383	14,584,171	174.9
	Total	193,383	21,059,984	108.9

Table 1-5. NECESSARY TIME FOR FLOOD PROTECTION WORKS

Work Item	Necessary Time
1. Data Collection, Processing, Filing and Calculation	2.5 days
(a) Data collection and transmission	1.8
- Recording of observation data - Communication from site to regional office - Communication from regional office to the Head Office - Delivery to the Data Processing Division	
(b) Filing, Processing and Calculation	0.7
- Data punching - Input data arrangement and computation	
2. Dissemination of Flood Prediction to Agencies Concerned	0.5 days
(a) Preparation of dissemination documents (b) Dissemination to agencies concerned	
3. Deliberation on Necessary Countermeasures	0.3 days
(a) Setting of meetings (b) Confirmation of the present flooding condition (c) Prospect of the future condition (d) Discussion and Decision on the necessary countermeasures	
4. Dissemination of Necessary Countermeasures	0.2 days
(a) Preparation of the dissemination document (b) Dissemination from Head Office to Branch Office	
5. Execution of Flood Protection Works	2.0 days
(a) Preparation for Flood Protection Works	0.2
- Arrangement of the flood information - Site inspection - Confirmation of the necessary flood protection works - Estimation of necessary manpower, materials and equipment	
(b) Mobilization for Flood Protection Works	0.3
- Preparation of manpower, materials and equipment - Transportation of manpower, materials and equipment	
(c) Execution of Flood Protection Works	1.5
- Execution of flood protection works - Evacuation of assets - Confirmation of the security of the flood protection works	
Total	5.5 days

Table 1-6. ABRUPT CHANGE OF FLOOD WATER STAGE

Year	C2 (Nakhon Sawan)			C13 (Chai Nat)			C7A (Ang Thong)		
	Date	Observed Water Stage (m)	Difference	Date	Observed Water Stage (m)	Difference	Date	Observed Water Stage (m)	Difference
1978	SEP 22 SEP 23	22.99 23.29	0.30	SEP 30 OCT 1	14.21 14.56	0.35	OCT 7 OCT 8	7.09 7.14	0.05
1980	SEP 21 SEP 22	23.52 23.80	0.28	OCT 3 OCT 4	14.79 15.26	0.47	OCT 3 OCT 4	7.07 7.19	0.12
1983	OCT 20 OCT 21	24.19 24.33	0.14	OCT 16 OCT 17	14.52 14.99	0.47	OCT 16 OCT 17	6.91 7.24	0.33

FIGURES

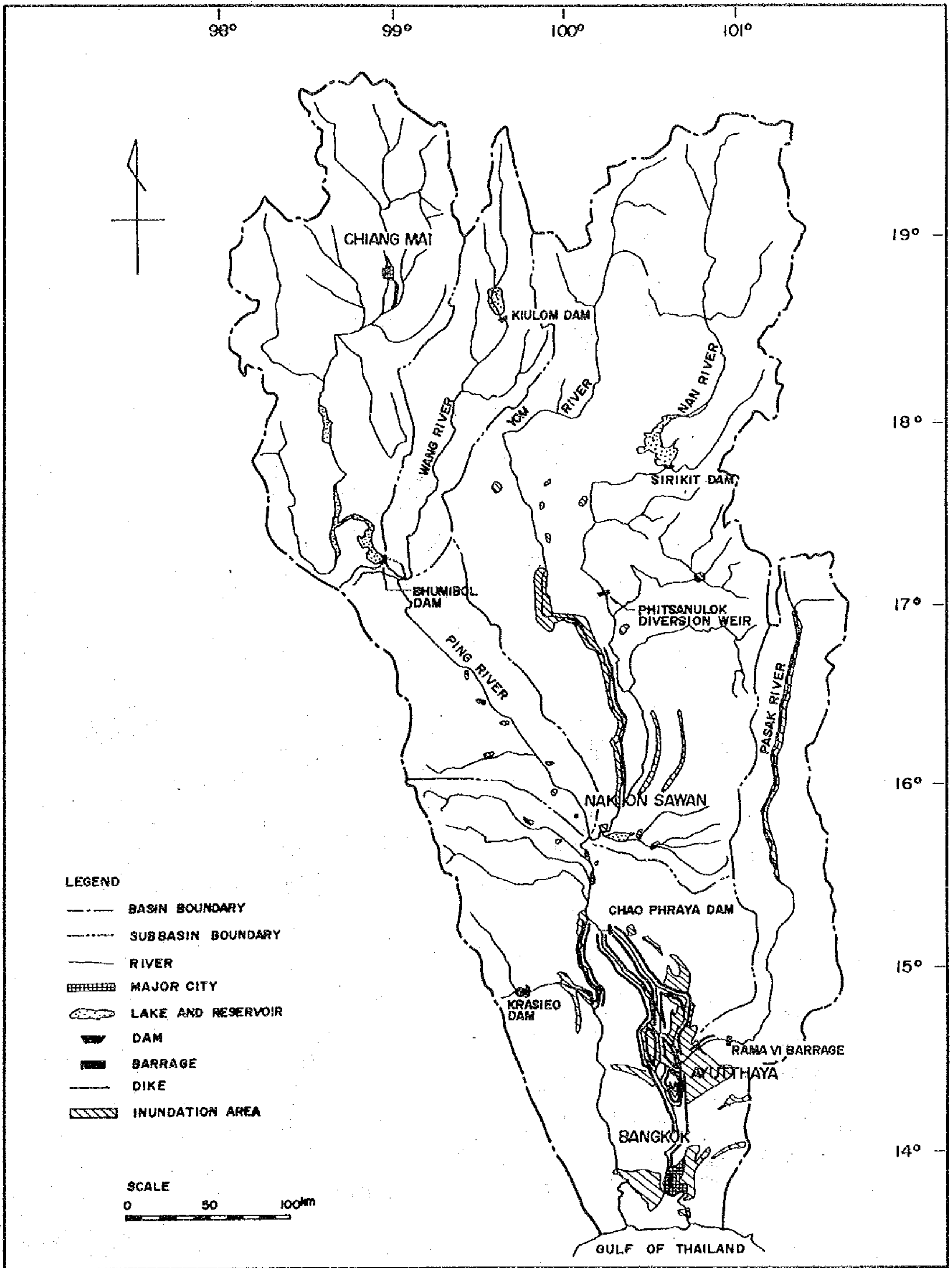

Fig. 1-1. INUNDATION AREA IN WHOLE BASIN

FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

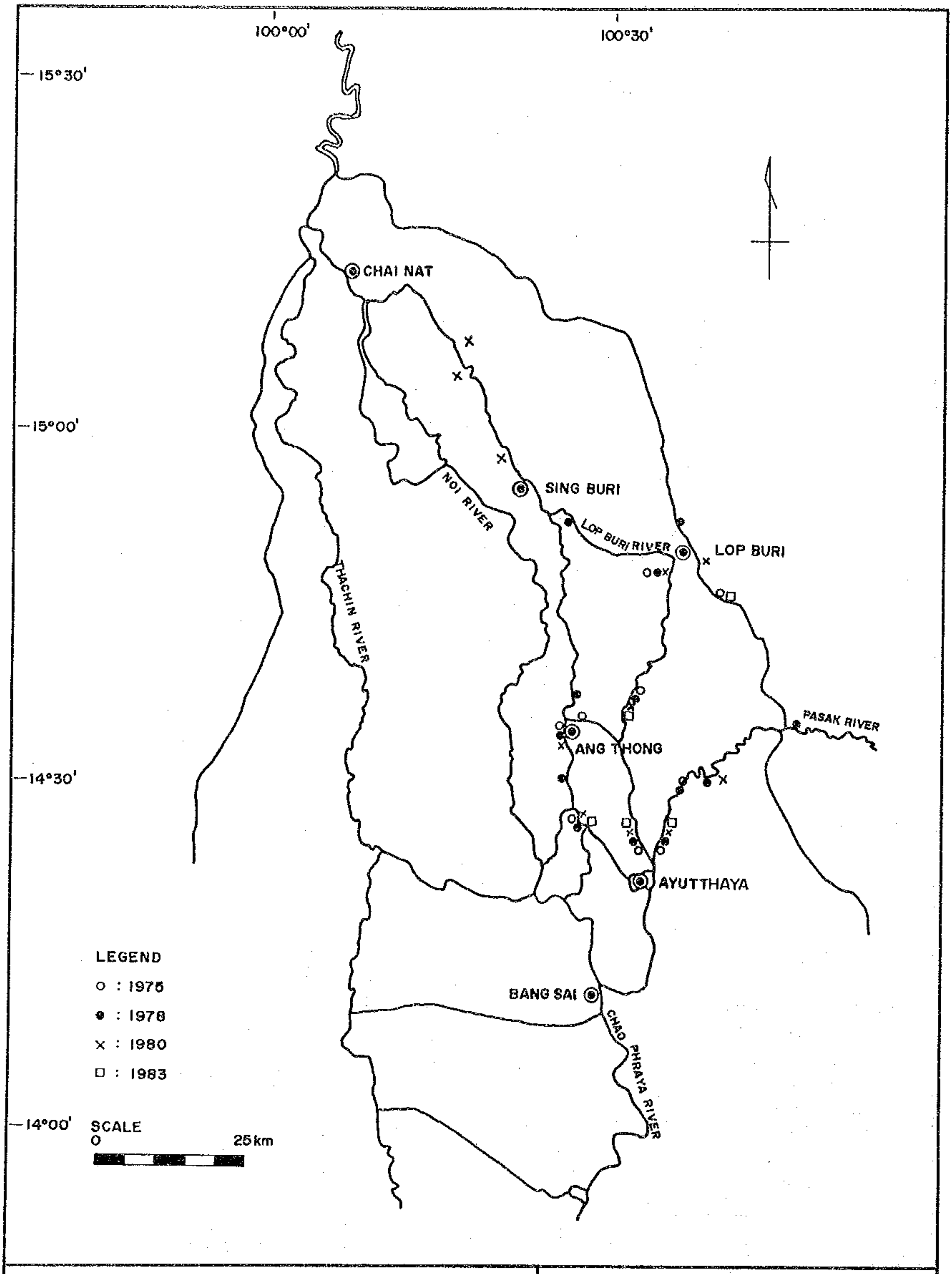

Fig. 1-2. OVERTOPPING POINTS OF FLOOD DISCHARGE

FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

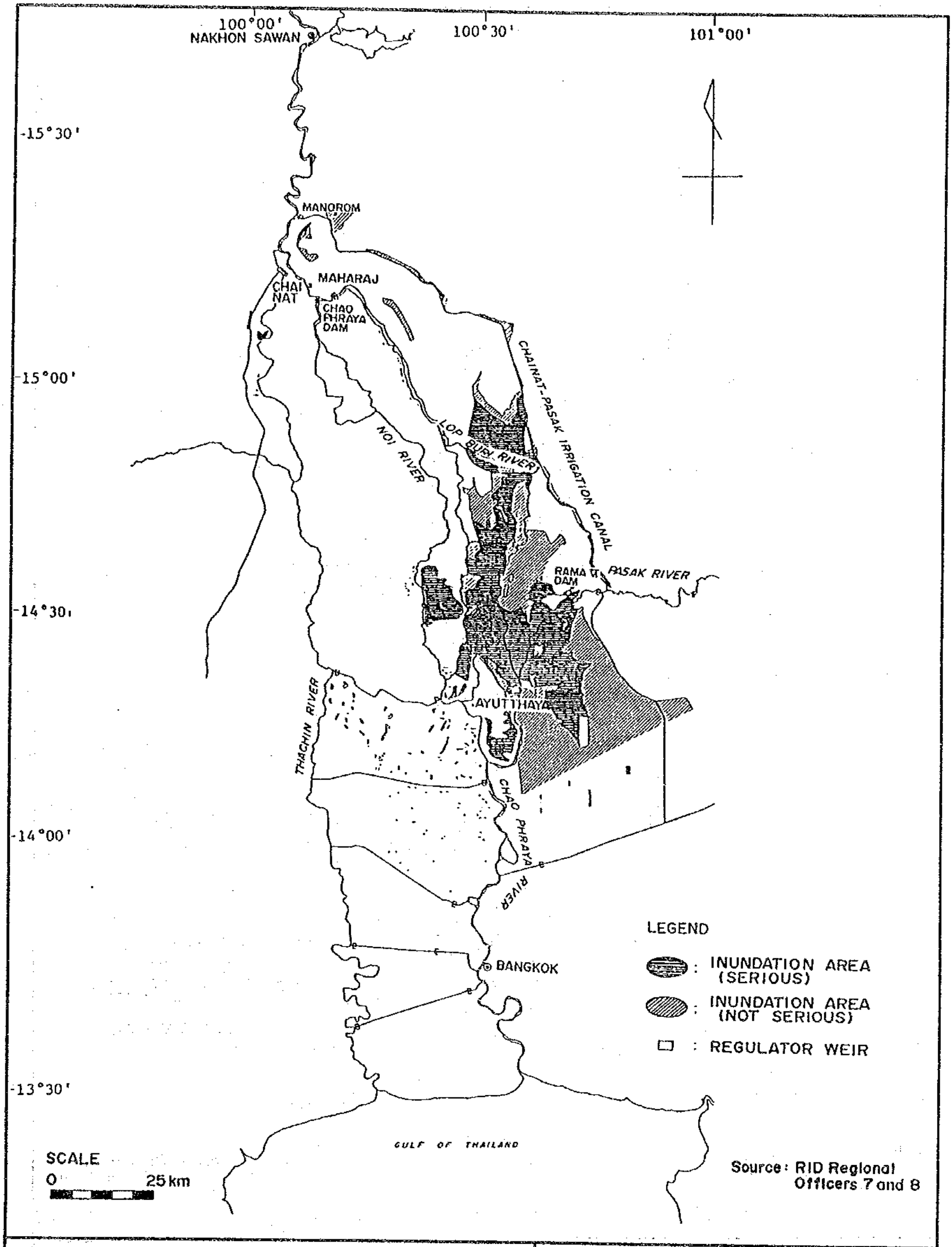

Fig. 1-3(1/3). INUNDATION MAP (1978 FLOOD)

FLOOD FORECASTING SYSTEM
IN THE CHAO PHRAYA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

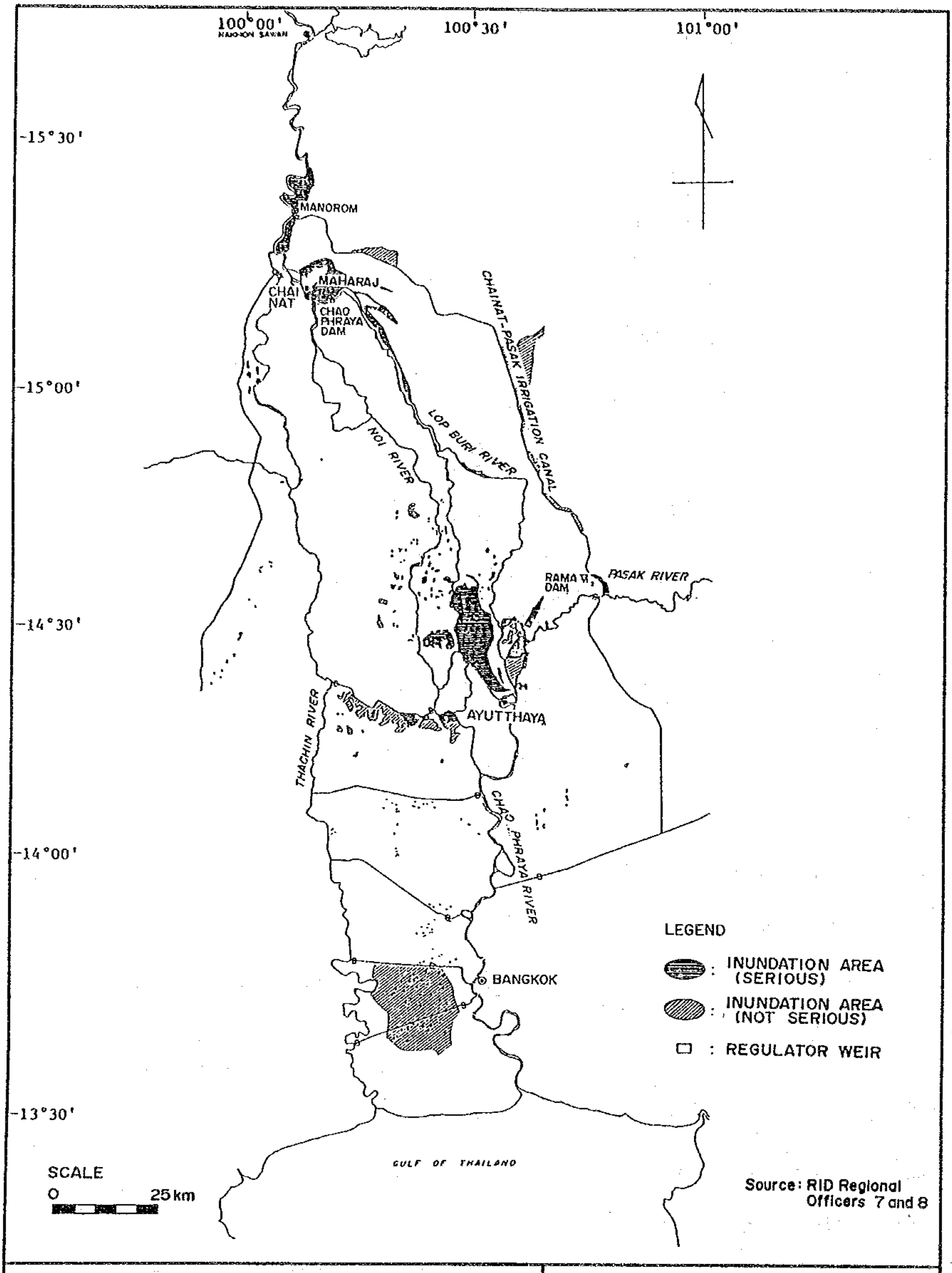

Fig. 1-3(2/3). INUNDATION MAP (1980 FLOOD)	FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN
	JAPAN INTERNATIONAL COOPERATION AGENCY

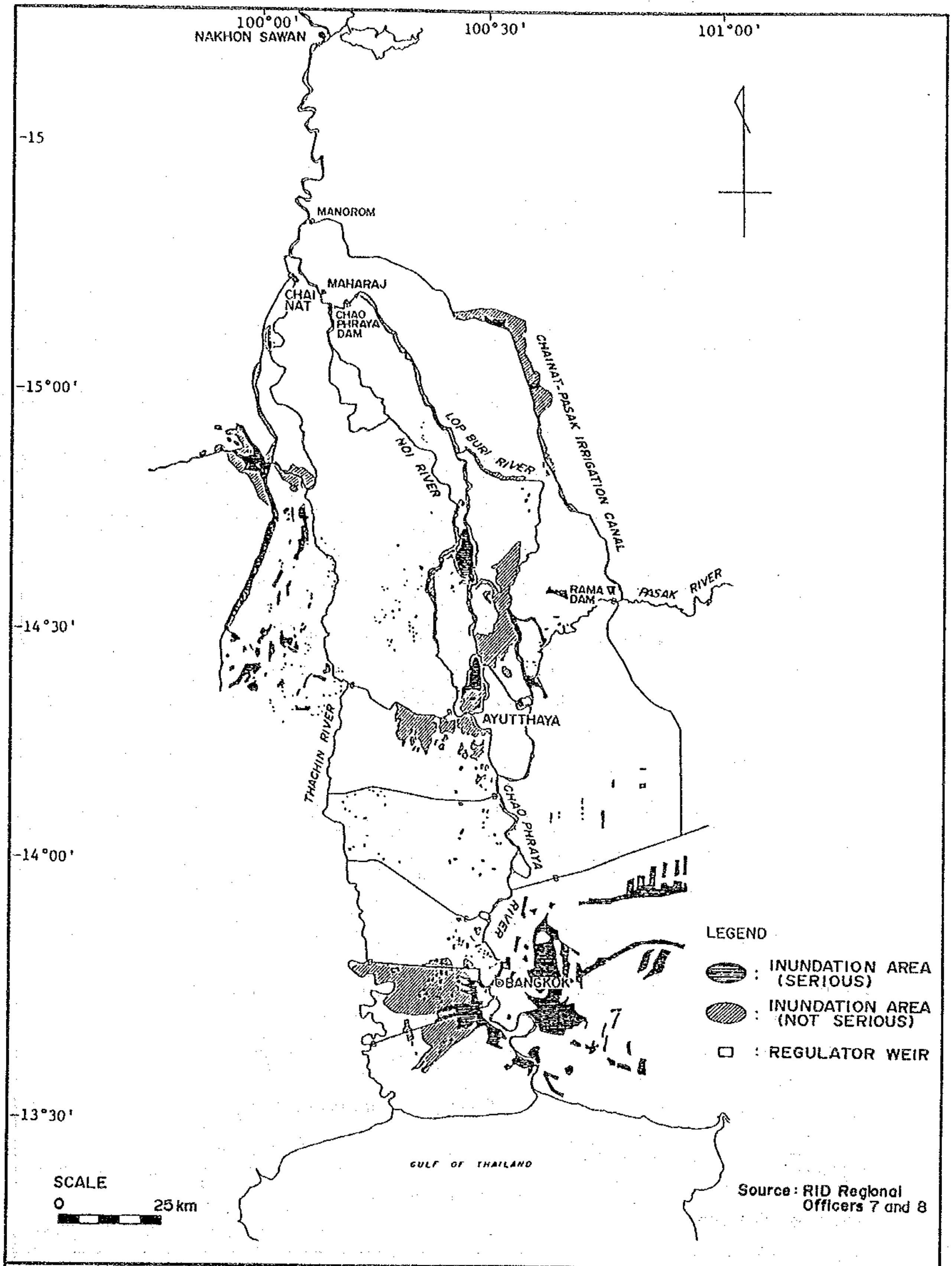

Fig. 1-3(3/3). INUNDATION MAP (1983 FLOOD)

FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

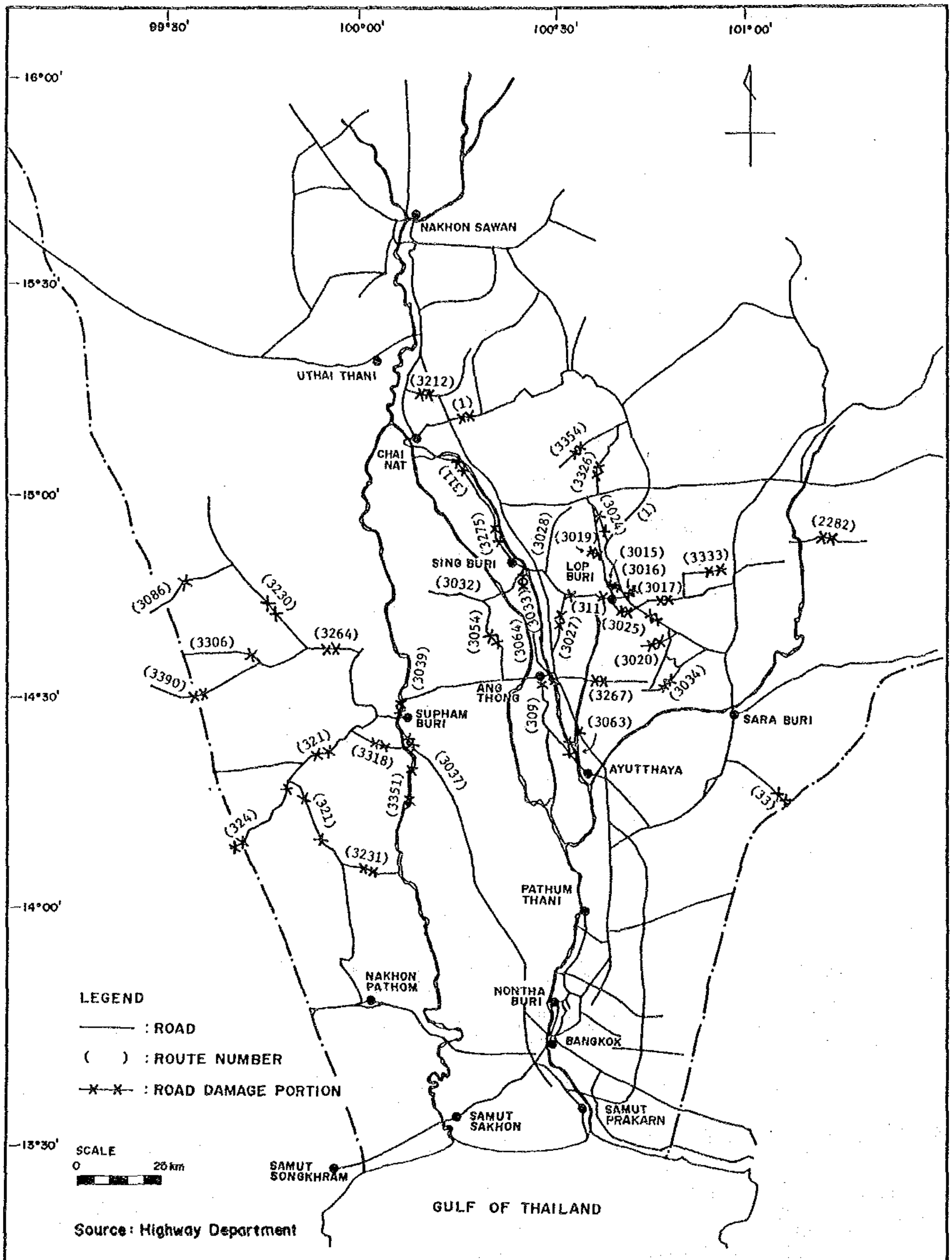

Fig. 1-4. FLOOD DAMAGED PORTIONS OF ROADS

FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

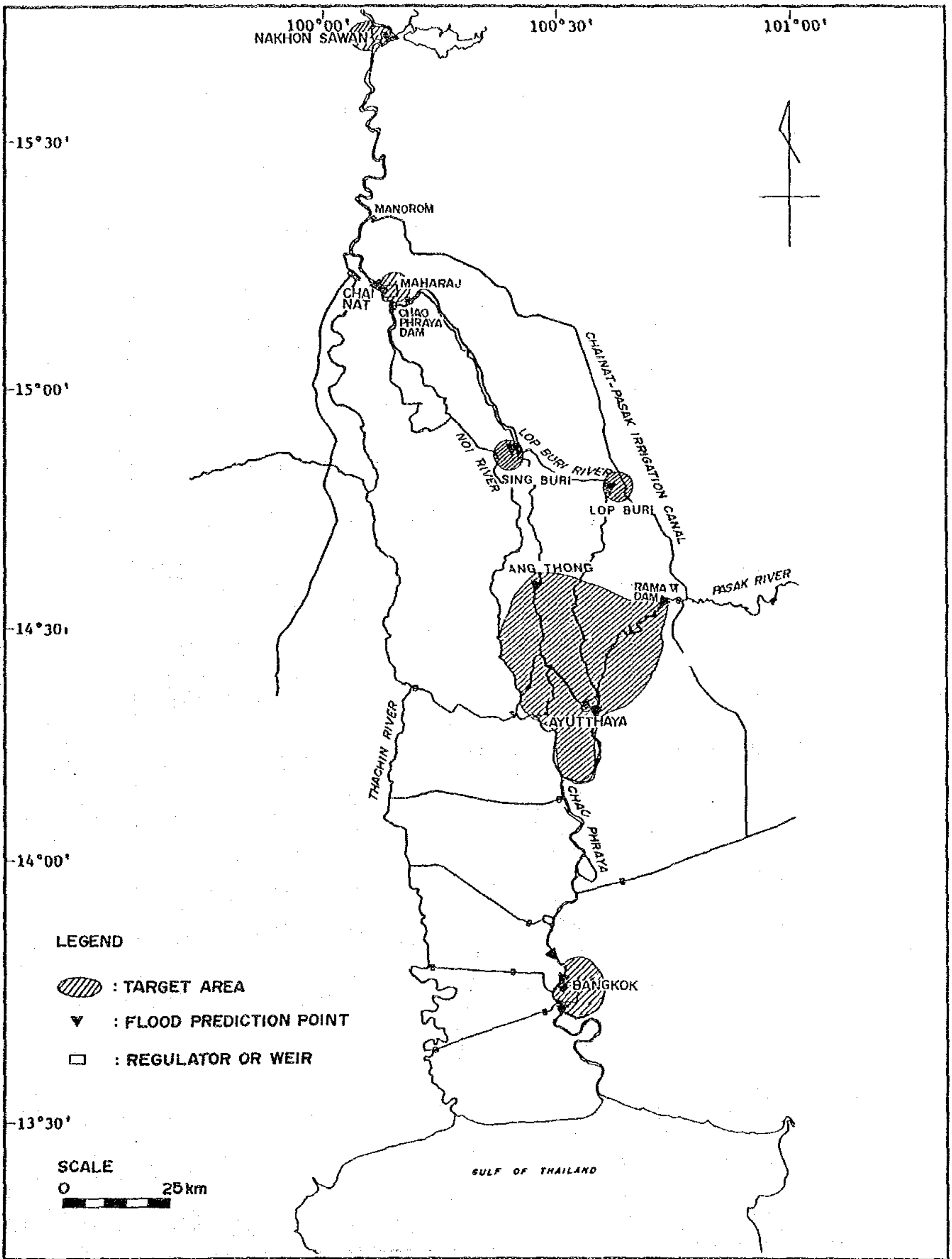

Fig. 1-5. TARGET AREA AND FLOOD PREDICTION POINTS	FLOOD FORECASTING SYSTEM IN THE CHAO PHRAYA RIVER BASIN . JAPAN INTERNATIONAL COOPERATION AGENCY

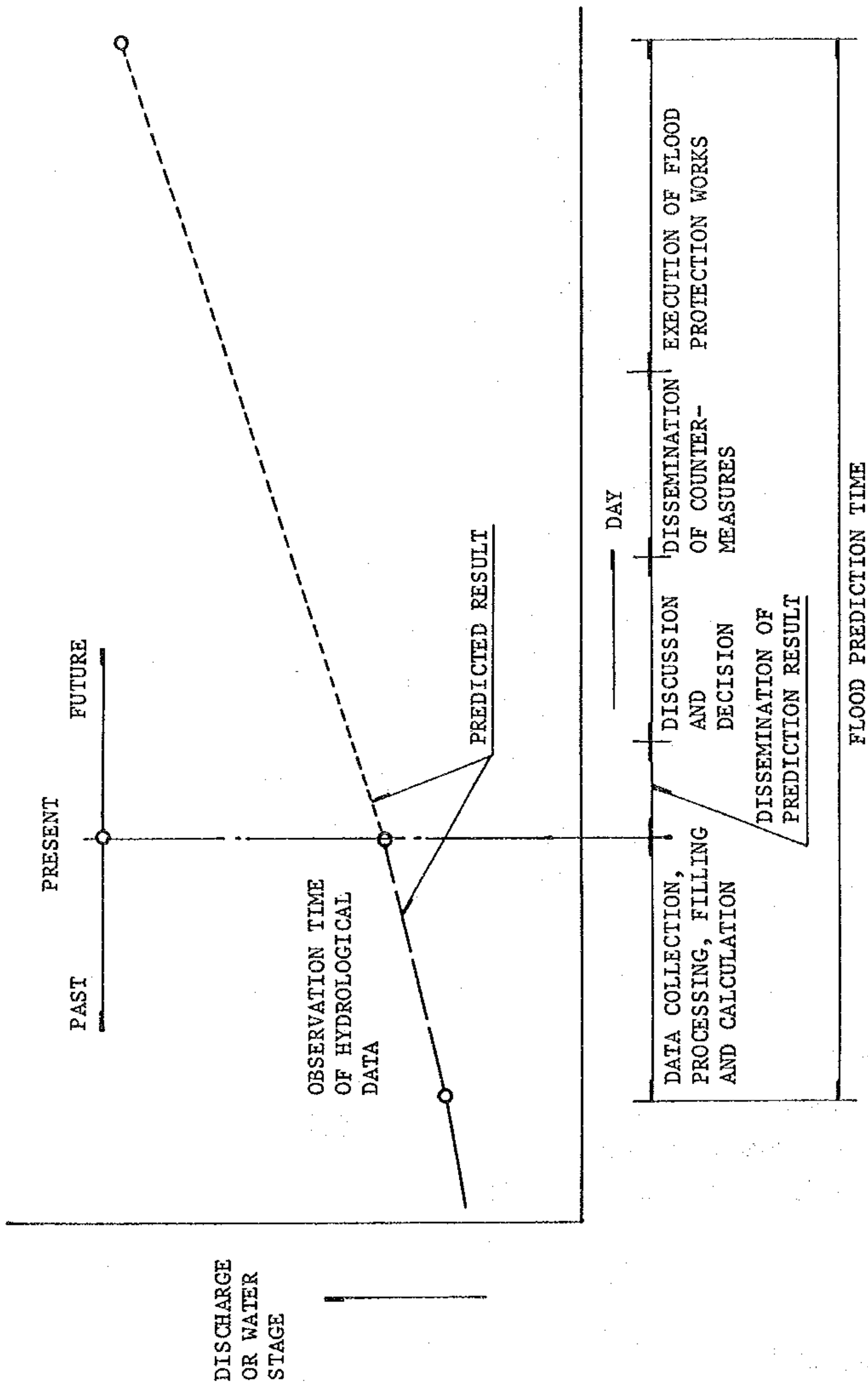

Fig. 1-6. FLOOD PREDICTION TIME

2. HYDROLOGY

SUPPORTING REPORT
ON
HYDROLOGY

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2. SUPPORTING REPORT ON HYDROLOGY

1. Meteohydrological Condition in the Basin

The Chao Phraya River Basin is located in the tropical monsoon region which has distinct dry and rainy seasons. The rainy season is brought by the southwest monsoon coming from the Indian Ocean during the period from April to October. The monsoon is laden with high moisture content and provides high values of precipitation and humidity.

During the rainy season, tropical cyclones often occur in the South Pacific Ocean and move into the basin, especially in September and October. Due to the tropical cyclonic disturbances, more widespread precipitation of longer duration can happen in the basin.

The dry season continues from November until March during which a dry and cold air mass is brought by the northwest monsoon from the China mainland (refer to Fig. 2-1). Consequently, the dry season provides low values of precipitation and humidity.

The annual rainfall in the basin varies from 1,000 mm in the western area to 1,400 mm in the northeastern area. About 85 percent of the annual rainfall occurs during the rainy season. During a tropical cyclone, one day precipitation sometimes exceeds 100 mm.

Temperature ranges from 27 to 32°C during the rainy season, while it drops into 20 to 27°C during the dry season (refer to Fig. 2-2). As for the areal variation, the temperature is rather uniform, except in the mountainous region around Chiang Mai.

Evaporation in the basin is normally at its highest in April and lowest in August to September (refer to Fig. 2-2). According to the records of a pan evaporation gauge, the average monthly evaporation varies from about 100 mm to 250 mm with annual totals of about 1,200 mm observed in the northeastern area to 2,000 mm in the inland areas. The areal variation in evaporation is rather small.

The river flow discharge shows a seasonal variation in accordance with the aforesaid distinctive precipitation in the rainy and dry seasons. It usually starts to increase in April, and reaches its peak in either September or October, when an intensive precipitation is caused by the tropical cyclonic disturbances.

The stream gauging station at Nakhon Sawan (Sta. C2) is regarded as a key station to overview the flood discharges from Ping, Yom and Nan. According to the records at the station, the maximum discharge was observed after construction of the Bhumibol and the Sirikit dams: at 4,355 m^3/s in 1975 and at 4,320 m^3/s in 1980. The maximum discharges were estimated at about 0.04 $m^3/s/km^2$ in terms of discharge per unit drainage area. Such a rather small discharge per unit drainage area is due to the large retarding effects, the extremely wide drainage area, and the gentle slope of the basin.

The tidal compartment is regarded approximately until Bang Sai on the Chao Phraya River and the Rama VI Dam on Pasak River. The mean high water and the mean low water spring tides are approximately 2.2 m and -1.8 m above MSL observed at the river mouth.

2. Existing Hydrological Observation Network

2.1 Rainfall Observation

The rainfall observation network consists of about 600 point gauging stations (refer to Fig. 2-3), about half of which are operated by RID and the other half by MD. In addition to these stations, some point gauging stations are operated by other agencies such as NEA, EGAT, PWD, etc. The gauging stations of MD are almost equally distributed in the upper and the lower reaches from Nakhon Sawan, while those of RID are mostly installed nearby the irrigation structures and biased to the delta areas in the lower reaches from Nakhon Sawan. Consequently, although about 400 gauging stations concentrate on the lower reaches within an area of about 50,000 km2, only about 200 gauging stations are in the upper reaches of about 110,000 km2.

The gauging stations equipped with telecommunication data transmission facilities are rather scarcely distributed in the upper reaches from Nakhon Sawan. Accordingly, difficulty is foreseeable in the collection of gauging data within a short period. On the other hand, telecommunication facilities are provided to more than 100 gauging stations in the lower reaches from Nakhon Sawan. Most of them are, however, useful for the management of irrigation water but not for the flood forecasting of the Chao Phraya River.

In addition to the aforesaid point rainfall gauging stations, MD also operates radar gauging stations at Bangkok and Chiang Mai. The information from radar gauges are only for qualitative analysis of precipitation in the basin but not for determination of quantitative areal precipitation.

2.2 Water Stage and Discharge Observation

There are 224 water stage gauging stations along the Chao Phraya River and its tributaries. Among them, 107 stations have periodical flow discharge measurements also by using a current meter.

The location of all the key gauging stations are shown in Fig. 2-4. The gauging stations are operated by RID, MD, PAT, EGAT and NEA. Judging from the locations of existing gauging stations, 39 stations operated by RID are regarded as the key stations to comprehend the flood runoff condition on the Chao Phraya main channel and its major tributaries, that is, Ping, Wang, Yom, Nan and Pasak. Other key stations are also pointed out to be the two stations operated by MD in the middle reaches of the Pasak River Basin, but their discharge data have not been provided since 1981. Tidal information is presently provided by six stations operated by PAT in the estuary of the Chao Phraya River Basin.

In view of the observation for flood discharges on the Chao Phraya and its major tributaries, the aforesaid present observation network is judged to have "blind spot areas" especially in the Pasak and the Sakae Krang river basins. The Pasak and the Sakae Krang river basins have the first and second largest drainage areas in the lower reaches from Nakhon Sawan, and the flood discharges in both basins are directly drained into the Chao Phraya River. Thus, the flood discharges in these basins are considered to have a large influence on the Chao Phraya River, while gauging stations are scarcely distributed in these basins.

Telecommunication facilities are scarcely provided to the water stage/discharge gauging stations in the upper reaches from Nakhon Sawan and will not be useful to forecast flood discharges from the Ping, Wang, Yom and Nan river basins. On the other hand, in the lower reaches from Nakhon Sawan, telecommunication facilities are provided to numerous gauging stations located along the irrigation canals. The observation data from the gauging stations in the lower reaches are, however, not effective to forecast the flood discharges on the Chao Phraya River and its major tributaries.

3. Flood Runoff Characteristics

Flood runoff characteristics in the basin were examined from the hydrological records of 1978, 1980 and 1983 to outline the necessary flood prediction models. The past hydrological records were collected from the existing 41 water level gauging stations and 139 rainfall gauging stations, taking into account the hydrological significance in location and validity in recording length. The location of these gauging stations are shown in Figs. 2-5 and 2-6.

As shown in Table 2-1, floods in 1978, 1980 and 1983 have the largest scale among the floods that occurred in the recent eight years. The annual maximum discharge in the three years run up to 3,300 m^3/s at the observation points of either Nakhon Sawan (Sta. C2) or Chao Phraya Dam (Sta. C13) along the Chao Phraya River, which approximately corresponds to the flow capacity of the Chao Phraya River.

3.1 Flood Runoff Characteristics in the Upper Reaches

The upper reaches from Nakhon Sawan has a total drainage area of about 110,000 km^2 which is roughly divided into 46,000 km^2 of the Ping/Wang River Basin, 22,000 km^2 of the Yom River Basin and 33,000 km^2 of the Nan River Basin. The flood hydrographs observed in these river basins are as shown in Fig. 2-7.

In Yom and Nan river basins, the flood discharge hydrographs, once steeply rising up along the upstream, tend to be leveled and quite slowly depressed along the downstream afterwards. Consequently, rather constant and large values of flood discharge flow into the Chao Phraya River for a long duration. From the Nan River, especially, the flood discharge of more than 1,000 m^3/s constantly run into the Chao Phraya River for a duration of more than 10 days. (Refer to Figs. 2-8 and 2-9.)

The above runoff characteristics may be attributed to large retarding effects. From the observed flow discharge conditions and the field reconnaissance, the major retarding areas in Yom and Nan river basins are approximately specified in the reach downstream from Sukhothai (Sta. Y4) to Sam Ngam (Sta. Y17) along the Yom River, and in the vicinity of Phichit (Sta. N10) along the Nan River.

As for Ping and Wang rivers, the hydrographs observed at most gauging stations show a rather abrupt ascent and descent (refer to Fig. 2-10). Certain retarding effects are found only around the confluence between Ping and Wang rivers where the peak flow discharges are rather depressed (refer to Table 2-2). The hydrographs of the Ping River are further directly propagated to the Chao Phraya River, so that the peak discharges at Nakhon Sawan (Sta. C2) are observed within 5 days after those observed at Sta. P7A (about 490 km upstream from Nakhon Sawan) on the Ping River (refer to Fig. 2-7). Thus, notable retarding effects are not seen in the Ping River Basin, except the area around the confluence with the Wang River.

As shown in Figs. 2-11 to 2-13, the Ping/Wang River Basin and the Yom/Nan River Basin tend to be separately covered with different occasional rainfall areas which lead to the different occasional peak discharge flows of the Ping River and the Yom/Nan River. The flood discharges of the Chao Phraya River at Nakhon Sawan are formed by composing such different occasional peak discharges provided from the respective tributaries in the upper reaches.

Throughout the floods of 1978, 1980 and 1983, it is concluded that large values of peak discharge at Nakhon Sawan will emerge through the following runoff pattern of the Yom, Nan and Ping rivers:

(1) Due to the dominant rainfall area, the Yom/Nan River Basin is firstly flooded, but the flood discharge is retarded in the lower reaches and a rather large flood discharge constantly flows into the Chao Phraya River for a rather long period.

(2) Succeedingly, another occasional rainfall causes a flood in the Ping River. Since there is no notable retarding effect in the Ping River Basin, the peak discharge is soon propagated into the Chao Phraya River and added to the aforesaid prolonged flood outflow discharges from Yom and Nan rivers.

3.2 Flood Runoff Characteristics in the Lower Reaches

The Pasak and Sakae Krang river basins are the major drainage areas for the Chao Phraya River in the lower reaches from Nakhon Sawan covering an area of about 14,400 km^2 and 3,900 km^2, respectively. Flood discharge from the Pasak and the Sakae Krang rivers is drained into the Chao Phraya River at points nearby Ayutthaya and the Chao Phraya Dam.

As shown in Table 2-3, a considerable flood discharge is drained from the Pasak River to the Chao Phraya River, especially in 1978 when the annual maximum discharge of about 3,200 m^3/s was recorded on the Pasak River at Saraburi (Sta. S9), which is nearly equal to the 3,540 m^3/s recorded on the Chao Phraya River at Nakhon Sawan. It is noted herein that the dominant rainfall area in the Pasak River Basin is independent from that in the upper reaches from Nakhon Sawan (refer to Figs. 2-11 to 2-13). Accordingly, the date of peak discharge on the Pasak River is not related to that on the Chao Phraya River at Nakhon Sawan.

In the Sakae Krang River Basin, there is no key stream gauging station to overview the flood runoff discharge totally drained from the basin. It is, however, observed in 1983 that there was an increase of about 1,500 m^3/s of peak discharge during the transition of hydrograph from Nakhon Sawan (Sta. C2) to Chao Phraya Dam (Sta. C13) along the Chao Phraya River (refer to Table 2-3). Since the Sakae Krang River Basin is the major drainage area for the Chao Phraya River between Sta. C2 and C13, the increment of peak discharge is mostly attributed to the runoff discharge from the Sakae Krang River Basin. Considering the range of 2,000 to 4,000 m^3/s in the peak discharge on the Chao Phraya River, the said runoff discharge from the Sakae Krang is regarded as a rather large value.

From the inundation maps of 1978, 1980 and 1983, it is observed that the large flood inundation areas extend along the Chao Phraya River from the Chao Phraya Dam to Bang Sai and along the Pasak River from the Rama VI Dam to the confluence with the Chao Phraya River. Due to the retarding effect of the flood inundation areas, a considerable depression of flood discharge is expected of the runoff from the upper reaches of either the Chao Phraya River or the Pasak River.

In the upper reaches from Bang Sai, tidal influence is nil and daily fluctuations in water level/discharge are scarcely observed. On the other hand, in the lower reaches from Bang Sai, water level is fairly affected by tidal influence, so that hourly water level fluctuation is distinguished, especially along the downstream of the Chao Phraya River from the river mouth to Bangkok (located about 40 to 70 km upstream from the river mouth).

4. Flood Prediction Model

4.1 The Flood Prediction Model as a Whole

As a whole, the flood prediction model is composed of four basic mathematical models, namely, the Basin Runoff Prediction Model, the River Channel Routing Model, the Flood Plain Routing Model and the Unsteady Flow Prediction Model. The purposes of the four models are as follows:

(1) Basin Runoff Prediction Model

The model is used to predict runoff discharge generated from rainfall in the respective catchment areas.

(2) River Channel Routing Model

The model is used to simulate the channel flow discharge along the river stretches where the channel storage function and tidal influences are regarded as nil.

(3) Flood Plain Routing Model

The model is used to simulate flow discharge in the offstream flood plain areas, and to predict outflow discharge returning to the river channel.

(4) Unsteady Flow Prediction Model

The model is used to predict hourly water level along the estuary influenced by tidal fluctuations. The model further attaches the function of tidal prediction at the Gulf which is given through the Harmonic Analysis and used as a downstream boundary condition for the model calculation.

In consideration of the flood runoff conditions in the Chao Phraya River Basin, the objectives of the Basin Runoff Prediction Model were arranged to be the 14 subbasins in the Ping, Wang, Yom, Nan, Pasak and Sakae Krang river basins (refer to Fig. 2-14). As the objectives of the Flood Plain Routing Prediction Model, four major flood plains were selected around (1) the downstream of Yom River from Sukhothai (Sta. Y4) to Sam Ngam (Sta. Y17), (2) the vicinity of Phitchit (Sta. N10) along the Nan River, (3) confluence of Ping and Nan rivers, and (4) the downstream of the Chao Phraya River from the Chao Phraya Dam (Sta. C13) to Bang Sai (Sta. C29) (refer to Fig. 2-15). With regard to the Unsteady Flow Prediction Model, the objective is the estuary of the Chao Phraya River from the river mouth to Bang Sai (refer to Fig. 2-15).

The systematic diagram of the flood prediction model as a whole, corresponding to the above arrangement of basic models, is shown in Figs. 2-16 and 2-17. In the flood prediction model as a whole, runoff discharges predicted by the Basin Runoff Prediction Model are fed as input of inflow discharges for the River Channel and Flood Plain Routing Model. Subsequently, the outflow discharges simulated through the River Channel and Flood Plain Routing Models are used as the boundary condition of the Unsteady Flow Prediction Model. The water levels along the estuary are finally predicted by the Unsteady Flow Prediction Model with the use of another boundary condition in terms of the predicted tidal fluctuation at the Gulf.

The theoretical concepts and governing equations of the above basic mathematical models are described in Sections 4.2 to 4-5, together with the assumptions made and solution methods.

4.2 Basin Runoff Prediction Model

4.2.1 Theoretical Concepts and Governing Equations

The Four-Serial Storage Tank Model is adopted to predict the runoff discharge generated from rainfall in the basin. In the model, the catchment of the basin is simulated by storage tanks having several outlet holes at their sides and bottoms, as shown in Fig. 2-18.

Rainfall firstly enters into the upmost tank, and either runs off through its side holes or infiltrates through its bottom holes into the lower tank. This runoff and infiltration process is subsequently repeated in the lower tanks.

Water assumed to be lost through evapo-transpiration is subtracted from the stored water in the tanks. The subtraction is firstly done from the storage in the upmost tank, but if the stored water is insufficient for the subtraction, the deficit is subtracted from the storage in the second tank. This process is repeated in the lower tanks until the assumed loss through evapo-transpiration is fully deducted from the storage in the tanks.

In the model, the size of outlet holes is made smaller as the tank is located in a lower position on the assumption that speed of runoff and infiltration decreases as the location of the aquifer in the basin becomes lower. Thus, the serial tanks are arranged so as the runoff from the upmost tank corresponds approximately to the surface flow discharge, while the runoffs from the second, third and fourth tanks correspond to either the intermediate or the base flow discharge.

The discharges from each runoff and infiltration hole are expressed in the following equations:

$$q(t) = (h(t)-H)\cdot a_1$$
$$i(t) = h(t)\cdot a_0 \qquad (4.1)$$

where, $q(t)$: Discharge from the runoff hole (mm/day)
$h(t)$: Storage depth in the tank (mm)
H : Constant for the runoff hole height (mm)
a_1 : Constant for the runoff multiplier (day^{-1})
$i(t)$: Discharge from the infiltration hole (mm/day)
a_0 : Constant for the infiltration multiplier (day^{-1})

The equation of continuity is also assumed as below:

$$r(t) - q(t) - i(t) = \frac{dh(t)}{dt} \qquad (4.2)$$

where, $r(t)$: Effective precipitation (mm)
(= Actual Precipitation - Evapo-transpiration)

Discharge of runoff [q(t)] and infiltration [i(t)] are defined from the above simultaneous equations (4.1 and 4.2), as follows:

<u>If $r(t) = 0$</u>

$$q(t) = a_1\cdot e^{-(a_0+a_1)\cdot t} - Ka$$
$$i(t) = a_0\cdot e^{-(a_0+a_1)\cdot t} + Ka \qquad (4.3)$$

If $r(t) \neq 0$

$$q(t) = a_1 \cdot Kb \cdot \int_0^\infty r(t-T) \cdot e^{-(a_0+a_1) \cdot T} \, dT - Ka$$

$$i(t) = a_0 \cdot Kb \cdot \int_0^\infty r(t-T) \cdot e^{-(a_0+a_1) \cdot T} \, dT + Ka$$

(4.4)

where, K_a and K_b are constants expressed as below.

$$Ka = a_0 \cdot a_1 \cdot H/(a_0+a_1)$$

$$Kb = (a_0+a_1)^{-1}$$

Equations (4.3) and (4.4) show that the runoff q(t) and infiltration i(t) are diminished in proportion to the exponential function with the index expressed by the sum of outlet multipliers, $(a_0 + a_1)$. Similarly, in the case of a tank having more than two runoff multipliers $(a_1, a_2, a_3, \ldots)$, the runoff $q(t)$ and infiltration $i(t)$ have the diminishing coefficient expressed by exponential function with the index of $(a_0 + a_1 + a_2 + \ldots)$.

4.2.2 Features of the Model

Since the aforesaid model has non-linear characteristics, a large number of trial and error simulation is required to determine the model constants such as multiplier and height of runoff and infiltration holes. However, the model has the specific features mentioned hereunder which are advantageous to express the runoff mechanism of the Chao Phraya River Basin. Accordingly, as far as the structure of the model is properly determined, the results of model simulation coincide well with the observed values.

(1) Due to the arrangement of the multiplier and height of runoff and infiltration holes in the upmost tank, the model can well express the phenomenon of initial runoff loss which is variable in compliance with rainfall hystenesis.

(2) The model contains plural runoff holes. Due to this mechanism, the model can well express the sensitive non-linear phenomena such as the increment of runoff discharges accelerated by the increment of rainfall and the demission of runoff discharges during non-rainy days.

(3) Due to the large catchment area, the major subbasins such as Ping, Yom, Nan and Pasak river basins cause different occasional peak discharge flows. Hence, the flood discharges on the Chao Phraya River are attributed to not only surface flow but also the intermediate and base flow in each subbasin. The said intermediate and base flow are well expressed by the arrangement of serial storage tanks in the model.

(4) The calculations in the model can be made only by simple arithmetic operations such as addition, subtraction and multiplication. Besides, the main parameter for calculations is set on only the storage depth in each tank. Accordingly, the feedback can be easily made by adjusting the storage depth corresponding to the observed value.

4.2.3 Verification of the Model

The constant parameters for the model equations were determined by trial simulations using the past hydrological records. The items of constants are the multipliers of each runoff hole and infiltration hole, and the height of each runoff hole from the bottom of the tank.

The periods of trial simulation are the typical flood years of 1978, 1980 and 1983. Hydrological records for the simulations include items such as daily average rainfall and evapo-transpiration as the input data, and runoff discharges for the verification of the results of simulation. The daily basin average rainfall was estimated by arithmetic mean point rainfall.

Daily evapo-transpiration was estimated from the observed pan evaporation and the annual hydrological balance between the annual total depth of rainfall and outflow discharge in a hydrological year (from April up to March of the following year). As shown in Table 2-4, the annual hydrological balance in each basin is a rather constant value which is regarded approximately as the actual annual evapo-transpiration volume in the basin. As for the pan evaporation data, both of their monthly and annual values are also rather constant as shown in Table 2-5.

The ratio of the annual hydrological balance to the annual pan evaporation volume is estimated at 50 to 60% for the respective subbasins (refer to Table 2-6). As a result of the estimations, the daily evapo-transpiration depths were determined as monthly constant values, through the following equation:

$$e(t) = E_{mpa} / N \times (E_{ahy} / E_{apa}) \qquad (4.5)$$

where, $e(t)$: Daily evapo-transpiration depth (mm/day)

E_{mpa} : Monthly pan evaporation depth (mm/month)

N : Number of days in a month

E_{ahy} : Annual hydrological balance (mm/year)

E_{apa} : Annual pan evaporation depth (mm/year)

Numerous trial simulations were made with the use of the above hydrological data, assuming various values of constants until the simulated hydrographs of runoff discharges were well fitted to the observed hydrographs. The simulation results are shown in Fig. 2-19, while the constants listed in Table 2-7 are the final values adopted to the model.

By using the constants adopted, the flood discharges were also simulated and compared with the observed values as shown in Table 2-8. Thus, a good coincidence was also given in the comparison.

4.3 River Channel Routing Model

The model is applied to the river stretches where the storage function of river channels and the tidal influences are regarded as nil. Thereby, the model is to express the transition of the river channel discharges simply by the following two elements, namely, (1) the traveling time of channel flow discharges, and (2) the relationship of channel flow discharges before and after overbanking.

4.3.1 Traveling Time of Channel Flow Discharge

According to the simulation results of the Basin Runoff Prediction Model, it is identified in several river stretches that the simulated flood peak discharges are propagated toward the downstream observation point subject to the negligible influence of channel storage function. The propagation takes a rather constant traveling time regardless of the flood occasion (refer to Table 2-8). From the above viewpoints, 17 river stretches were selected through trial simulation to arrive at a constant traveling time. The location of the river stretches and the traveling time assumed for each river stretch are as shown in Fig. 2-16 and 2-17 and Table 2-9, respectively.

4.3.2 Relationship of Channel Flow Discharges Before and After Overbanking

On the basis of the trial simulation, 11 overbanking points were assumed to the model (refer to Figs. 2-16 and 2-17). Thereby, the channel flow discharges before and after overbanking can be expressed simply by the linear relationships, as shown in Fig. 2-20. The overbanking discharges are herein assumed to be either the pondage or the offstream flood plain flow which is to be simulated by the Flood Plain Routing Model mentioned in Section 4.4.

4.4 Flood Plain Routing Model

The model is used to predict outflow discharges from the four (4) major flood plains specified in Section 4.1.

4.4.1 Theoretical Concepts and Governing Equations

There is a non-linear type characteristic in the runoff phenomena to be influenced by the retarding effects. To express the characteristics, the aforesaid objective section is divided into several storage containers, and the outflow discharges from each container are assumed to have the following relationship with their corresponding storage volumes.

$$S(t) = K.Q\,(t + T1)^{p} \qquad (4.6)$$

where, $S(t)$: Storage volume in one container at time t

k, p : Constants

$Q(t+T1)$: Outflow discharge from the container at time $(t + T1)$

$T1$: Lag time

The equation of continuity in each storage container is also expressed as below:

$$dS(t)/dt = I(t) - Q(t + T1 + T1z) \qquad (4.7)$$

where, $I(t)$: Inflow discharge to the container at time t

$dS(t)/dt$: Differential of storage volume by time

$T1z$: Apparent lag time

The outflow discharges from the container are calculated through the above equations from the known quantities of inflow discharges, using a storage volume as the medium function. The objective sections to be applied to the model are divided into several storage containers, which are expressed by the river stretch assuming storage function as shown in Figs. 2-16 and 2-17. The manner of container arrangement is described later.

The inflow discharges at the upmost stream container are given as the boundary conditions by the runoff discharges simulated by the Basin Runoff Prediction Model and the River Channel Routing Model. On the basis of the boundary conditions, the outflow discharges from the upmost stream container are calculated through the above equations and input to the next downstream container as the inflow discharges. Thus, the outflow discharges are repeatedly calculated in the downward containers on the basis of the outflow discharges calculated from the upward container.

The section of the Chao Phraya River between the Chao Phraya Dam and Bang Sai has the river channel network composed of several diversion channels, as shown in Fig. 2-17. To know the diversion ratio of the calculated outflow discharges from the upper container, the non-uniform calculation was made on the basis of the river channel survey results obtained in this study period. As the results, the diversion discharges to each channel are given, as shown in Fig. 2-21.

The constant parameters of "k", "p", "Tl" and "Tlz" in the above equation (4.6) were determined as shown in Table 2-10 on the basis of the relationship between the outflow discharge and its corresponding storage volume in each storage container. The said hydrological relationship was derived from the following data.

(1) As for the storage container for Code No. S5 (refer to Fig. 2-16), the data are the outflow discharge hydrographs observed at Nakhon Sawan (Sta. C2) and the simulated inflow discharges from the Ping, Yom and Nan rivers (refer to Fig. 2-22).

(2) As for the storage containers except Code No. S5, since the observed discharge hydrographs are not available, the following data are substituted:

(a) The river channel flow discharge and its corresponding storage volume which were estimated from the aforesaid non-uniform calculation (refer to Fig. 2-23 and Table 2-11).

(b) The offstream flow discharge and its corresponding storage volume in the flood plain which were estimated from the river channel survey results and the topographic map on a scale of 1/150,000.

4.4.2 Configuration of the Model

The following points were taken into consideration for the model shown in Figs. 2-16 and 2-17.

(1) The Section of Yom River Between Si Satchanalai (Sta. Y14) and San Ngam (Sta. Y17) (Section Code Nos. S1 and S2)

(a) Overbanking of the flood discharge is presumed to occur in the section between Sta. Y14 and Sta. Y4. The overbanking discharge is expected to return through the flood plain area to the river channel between Sta. Y4 and Sta. Y17.

(b) The runoff discharge caused by local rainfall may also flow into the river channel between Sta. Y14 and Sta. Y17.

(2) The Section of Nan River Between Phitsanulok (STa. N5A) and Thaphan Hin (Sta. N10A) (Section Code Nos. S3 and S4)

(a) The flood plain spreads widely eastward to Nan River. Thereby, the runoff discharge caused by local rainfall flows into the river channel subject to the remarkable regulation effects through the flood plain.

(b) Judging from the discharge hydrographs observed at Sta. N10A, the discharges of more than 1,400 m^3/s

will overbank along this section and afterwards return to the downstream river channel.

(3) Confluence of Ping and Nan Rivers (Section Code No. S5)

(a) Judging from the comparison between the observed discharge hydrographs at Nakhon Sawan (Sta. C2) and the simulated discharge hydrographs of Ping and Nan rivers, it is necessary to conceive a certain retarding effect around the junction of the Ping River, the Nan River and the Chao Phraya River.

(b) The retarding effect is estimated to start when the discharge of more than 1,100 m3/s flow down from the Ping and Nan rivers.

(4) The Section of Chao Phraya River Between Chai Nat (Sta. C13) and Bang Sai (Sta. C29) (Section Code Nos. S7 to S22)

(a) Flooding conditions in this section are basically governed by the flood discharge flowing from the Chao Phraya Dam on the Chao Phraya River, Rama VI Dam on the Pasak River and Phakhai Regulator on the Noi River. The flood discharge caused by local rainfall is nil compared with the flood discharge volume from the above-said points.

(b) The river channel network consists of several diversion channels and the diversion ratio of flood discharge among these channels has much influence for the calculation of the flood discharge flowing to the lower reaches.

4.4.3 Features of the Model

The flood retarding simulation can be made by the various calculation models such as (1) Empirical Water Stage or Flood Discharge Correlation Model, (2) Muskingum Model, (3) Storage Function Model, and (4) Unsteady Flow Calculation Model.

Among these models which have their individual advantages and disadvantages, the Storage Function Model was applied due to the following advantages:

(1) The calculation method is not complicated.

(2) Through the modification of parameters, the method can easily deal with changes in runoff condition to be caused by river improvement.

(3) In case that there is much difference between the calculated value and the observed value at the prediction and calibration points, modification of the calculated value to correspond with the observed one is easily performed.

4.4.4 Verification of the Model

Simulations of the past flood phenomena were made through the proposed Flood Plain Routing Model together with the Basin Runoff Prediction Model and the River Channel Routing Model, as shown in Fig. 2-24 and Table 2-12, so as to verify the adequacy of the model and its parameters. Judging from the good coincidences between the simulated and observed discharge hydrographs in all simulations, it is evaluated that the proposed model is applicable to the prediction. It is noted herein that the verification at Bang Sai was made only on the basis of discharges estimated from the rating curves in 1970 and 1978 (refer to Fig. 2-25). Furthermore, since the rating curve at Bang Sai Station has not been well arranged due to instability caused by tidal influence, the reliability of the flood discharge converted from the observed water stage for use in the verification is not so high that the adequacy of the model is hardly identified. However, as far as the peak discharge and its occurrence time which are not affected so much by tidal influence are concerned, the calculated discharge relatively well coincides with the observed one.

4.5 Unsteady Flow Prediction Model

4.5.1 Theoretical Concepts and Governing Equations

The model is developed to express the fluctuations of water level along the estuary which are governed by the propagation of tidal waves in the Gulf. The hydraulic propagation can be conventionally calculated by the following unsteady free surface equations:

Equation of Continuity:

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = 0 \qquad (4.8)$$

Equation of Motion:

$$\frac{1}{gA}\frac{\partial Q}{\partial t} - \frac{2QB}{gA^2}\frac{\partial H}{\partial t} - \frac{Q^2B}{gA^2}\left(i + \frac{\partial H}{\partial x}\right) + \frac{\partial H}{\partial x} + n^2\frac{|Q|Q}{A^2R^{4/3}} = 0 \qquad (4.9)$$

where,
- Q : Flow discharge
- H : Water level
- g : Gravity acceleration
- A : Discharge flow area
- B : Width of water surface
- t : time
- i : Channel slope
- x : distance
- R : Hydraulic radius
- n : Manning's Roughness Coefficient

The momental water level (H) is successively calculated through the above equations from time to time and from the downstream point upwards. In the selection of equations, it is necessary to set up various given conditions such as the hydraulic dimensions of river channel, the appropriate

Manning's Roughness Coefficient, the initial condition of water level profile, and the boundary conditions. The contents of the above conditions are described hereinafter.

The hydraulic dimensions of river channel is used to correlate the water level and its corresponding hydraulic values such as discharge flow area (A), width of water surface (B) and hydraulic radius (R). The hydraulic dimensions were provided with the results of the river channel survey in 1980.

In the equations, the Manning's Roughness Coefficient is the controlling parameter of the computed water levels along the estuary. In this connection, the appropriate value of Manning's Roughness Coefficient is determined by simulations using the previous hydrological records. Details of the simulations are mentioned later.

The initial condition is given as the water level profile at the time before starting calculations for the river stretch from the river mouth to Bang Sai. The water level profile is to be consecutively provided from the hourly water levels observed at the stations along the estuary, so that the water level prediction in the model can be calibrated.

The boundary conditions are given in terms of the runoff discharges predicted at the upmost point of the estuary and the tidal levels predicted at the lowest point of the estuary. The runoff discharges are predicted at Bang Sai as the daily variables by the Basin Runoff Prediction Model, the River Channel Routing Model and the Flood Plain Routing Model. On the other hand, the tidal levels are predicted at the Gulf of Thailand as the hourly variables by the Harmonic Analysis.

In the Harmonic Analysis, it is assumed that tidal fluctuations periodically occur due to attracting forces by the sun and the moon. On the basis of the assumption, the hourly tidal levels are predicted by the following equation which is subject to a tidal composition of 61 harmonic constituents:

$$h(t) = \sum_{i=1}^{60} Hi \sin(\frac{2 \cdot \pi}{Ti} \cdot t + Ri) + H_{61} \qquad (4.10)$$

where, $h(t)$: Tidal level at time t starting from the specified standard time (m)

H_i : Amplitude of the ith constituent (m)

T_i : Cycle of the ith constituent (hour)

R_i : Phase (delay of angle) of the ith constituent at the specified standard time (radian)

The cycle of each constituent (T_i) is a known quantity which is given from astronomical phenomena. The constants of the amplitude (H_i) and the phase (R_i) can be determined for each corresponding (T_i) by using the previous tidal records of a fairly long period.

4.5.2 Verification of the Model

Verifications were made on the effects of the Manning's Roughness Coefficient in the aforesaid unsteady free surface equations, and also on the applicability of the tidal prediction achieved by the Harmonic Analysis.

Effects of Manning's Roughness Coefficient

The simulation of the unsteady flow condition along the estuary was made for the days when the annual maximum discharges in 1978, 1980 and 1983 were observed at Bang Sai. In this simulation, the boundary conditions were given from the daily runoff discharges observed at Bang Sai and the hourly tidal levels at Fort Phra Chul (located about 1.0 km from the river mouth).

Fig. 2-26 and Table 2-13 show the effects of roughness coefficient on the simulated water surface profiles of one-day maximum values along the estuary from the river mouth to Bang Sai. As shown in Fig. 2-26, the roughness coefficient of 0.024 can generate the best coincidence between the simulated and observed one-day maximum water levels for the section from the river mouth up to Pakred (located about 70 km from the river mouth). It is, however, noted that the roughness coefficient of more than 0.026 can generate a better coincidence at Bang Sai, the upmost point of the estuary (located about 110 km upstream of the river mouth).

The hourly water level hydrographs were also simulated at the points of Bangkok Port and Sathu Pradit which are located about 27 km and 40 km upstream of the river mouth, respectively. As shown in Figs. 2-27(1/3) and 2-27(2/3), the hydrographs simulated by the roughness coefficient of 0.024 has the good fitness with the observed hydrographs, especially for the part of their ascent limb. The hourly water level hydrographs at Bang Sai are further simulated as shown in Fig. 2-27(3/3), where the best fitness between the simulated and observed hydrographs is given by the roughness coefficient of 0.028.

As a result of the above simulations, the following matters were verified:

(a) The proposed unsteady flow calculation model will enable prediction of one-day maximum water level and its occurrence time by using the roughness coefficient of 0.024, at least for the river stretch from the river mouth to Pakred which covers the Bangkok target area.

(b) The roughness coefficient of 0.024 will also enable prediction of the water level hydrograph for the river stretch around Memorial Bridge (located about 50 km from the river mouth). Thereby, better accuracy is expected in the prediction for the ascent limb of the hydrograph.

(c) The results of the simulation of Bang Sai suggest that the roughness coefficient of more than 0.024 will be required for the prediction along the upper stream from the Bangkok target area.

Effects of Tidal Prediction

Table 2-14 shows the constants of the amplitude and the phase for each corresponding cycle of constituents. The constants were determined through Harmonic Analysis on the basis of the tidal records at Fort Phra Chul in 1977, 1979 and 1982, and used to predict the hourly tidal levels in the following years of tidal recording, namely, 1978, 1980 and 1983.

By using the constants determined, the hourly tidal level hydrographs were predicted for the days in either the month of rainy season (October) or the month of dry season (January), as shown in Fig. 2-28. The one-day maximum and minimum tidal levels through a year are also predicted, as shown in Fig. 2-29 and Table 2-15.

As the results of the above prediction, it is concluded that there are still about 60 days in a year having the difference of more than 30 cm in the observed and predicted one-day maximum water level (refer to Table 2-16).

One of the reasons for the above difference is attributed to the meteorological tidal deviations governed by the wind and air pressure. In this connection, it was attempted to reduce the difference through the correlation analysis based on the following equation:

$$dH(t) = Ka \cdot dP + Kb \cdot W^2 \cdot COS^2 x \qquad (4.11)$$

where, dH(t): The difference of tidal levels observed and predicted by the Harmonic Analysis at time t

dp : Drop in atmospheric pressure (mb)

W : Wind velocity (m/s)

x : Angle between wind direction and coastline

Ka,Kb: Constant parameter

The definite values of the above constant parameters "Ka" and "Kb", were, however, not obtained during this study period due to the following conditions:

(1) The data of atmospheric pressure and wind were collected from the records in 1978, 1980 and 1983. However, these data contained rather small variations of the drop in atmospheric pressure and wind velocity.

(2) The study was done by using the data of wind velocity which was recorded at the Bangkok Meteorological Office. However, the wind condition in the gulf may be rather different from that at the office.

From the above viewpoints, it is desirable to have a further study on the matter of meteorological tidal deviations by using the data recorded at the river mouth for a longer period.

5. Step 1 Hydrological Gauging System

Hydrological observation points for use in the proposed flood prediction models are selected in consideration of their strategic location. Special attention is paid to the selection so as to immediately set up the Step 1 Flood Forecasting System and maintain it until the proposed Step 2 Flood Forecasting System is established. In this connection, the following conditions are taken into account:

(1) Availability for immediate and effective use of existing gauging facilities and their existing data transmission facilities with least rehabilitation or modification; and

(2) Applicability of the organization operating the existing gauging facilities.

Correspondingly, 31 water level gauging stations which include a tidal gauging station and 34 rainfall gauging stations are selected from the gauging stations operated by RID, the Meteorological Department (MD) and the Port Authority of Thailand (PAT). The details of the proposed gauging stations are described hereinafter, and their inventory and location are in Tables 2-17 and 2-18, and in Fig. 2-30.

5.1 Selection of Water Level Gauging Stations

The water level gauging points are selected in view of the following necessities of their gauging data:

(1) To calibrate the initial conditions for the simulations in the flood prediction models (refer to Table 2-19);

(2) To input the boundary condition in terms of runoff discharges observed in the upper reaches (refer to Table 2-20);

(3) To accommodate the basic data for the tidal prediction in the Gulf of Thailand; and

(4) To monitor the water level/discharges at the respective prediction points (refer to Table 2-19).

In the selection, the availability of the existing gauging stations are considered. Priority is given to the existing gauging stations operated by the Hydrology Division of RID, since most of the necessary gauging points are located at these stations. The water levels gauged by the Division are, however, presently transmitted by mail to the RID Head Office in Bangkok which has to be replaced by a more suitable and quicker data transmission method useful for the flood prediction purpose. Furthermore, the existing hydrological observation of the Hydrology Division contains blind spot areas in the Pasak and the Sakae Krang river basins.

In view of the blind spot areas, the two existing gauging stations operated by the Meteorological Department are selected for gauging in the middle reaches of the Pasak River Basin. As for the Sakae Krang River Basin, it is proposed to resume the water level gauging and discharge measurement at Sta. Ct8 previously operated by the Hydrology Division of RID, the gauging works of which were suspended since 1980. In addition to the river flow gauging, the tidal level in the Gulf of Thailand is further proposed to be gauged at Fort Phra Chul which is operated by the Port Authority of Thailand.

5.2 Selection of Rainfall Gauging Stations

Rainfall gauging stations will be used to estimate the areal average rainfall for the 12 subbasins where the Basin Runoff Prediction Model is applied. It is herein noted that 14 subbasins are finally proposed as the objectives of the model calculation in the Step 2 Flood Forecasting System, while 2 subbasins covering the catchment areas of the Bhumibol and Sirikit dams (Basin Code No. BS-1 and BS-7) are excluded from the objectives in the Step 1 Flood Forecasting System assuming that the discharge released from the dams are given to the model calculation as boundary conditions.

In the selection of the proposed gauging stations, priority is given to the availability of the existing gauging facilities, as well as the data transmission facilities. Correspondingly, the stations were selected as follows (refer to Table 2-21):

(1) The 10 rainfall gauging stations located nearby the water level gauging stations selected in the foregoing, considering that the data transmission facilities employed by the water level gauging stations can be used in common with these rainfall gauging stations; and

(2) The 18 rainfall gauging stations attached to either the Meteorological Department or the regional offices of RID which are presently able to transmit the gauged data to their head offices in Bangkok within one day through their own existing data transmission facilities.

In the selection made above, the rainfall gauging points could be rather uniformly distributed in the respective subbasins, except the Sakae Krang River Basin. To make up for the lack of gauging stations in the Sakae Krang River Basin, six (6) gauging points are additionally selected from the existing gauging stations operated by the Hydrology Division of RID which solely exist in the basin but do not possess the available data transmission system. Therefore, the selected gauging stations in the Sakae Krang River Basin are subject to the data transmission system newly provided.

5.3 Manner of Flood Prediction

The results of flood prediction at the respective prediction points are calculated in terms of either the daily average or hourly average water levels and discharges on the basis of the different combinations of the gauged data and the flood prediction models, as described hereinafter.

5.3.1 Prediction of Daily Average Water Level and Discharge

The prediction of the daily average water level/runoff discharge is to be provided to the prediction points except Bangkok. To perform the prediction, water level and the one-day rainfall data are collected from the hydrological gauging stations selected in the upper reaches from Bang Sai where the tidal influence is nil during the flood season. The hydrological data need to be simultaneously gauged once everyday and transmitted to the Bangkok Head Office within two days. The gauging time is herein assumed at every 9:00 a.m.

After collecting the data, the gauged water level and one-day rainfall are respectively processed to the runoff discharges (through rating curves) and the areal average rainfall. Subsequently, the runoff discharges generated from rainfall are predicted for each subbasin through the Basin Runoff Prediction Model (refer to Section 4.2). Further, the flood routing calculations along river channels and flood plains are made through the Channel Routing Model and the Flood Plain Routing Model (refer to Sections 4.3 and 4.4. Correspondingly, the daily average runoff discharges are predicted in advance of the actual flood runoff occurrence at the respective prediction points.

5.3.2 Prediction of Hourly Average Water Level

Bangkok, the first priority prediction point, is located along the estuary of the Chao Phraya River where the hourly water level is predicted by the Unsteady Flood Prediction Model with special attention to the tidal fluctuation (refer to Section 4.5).

In the Unsteady Flow Prediction Model, it is first required to calibrate the initial condition, i.e., the water level profile along the river stretch from the river mouth to Bang Sai at the time before starting the model calculation. Due to the required calibration, the hourly observed water levels are needed. Therefore, it is proposed to record the hourly gauged water levels by the automatic recorder at the existing four gauging stations, namely, Fort Phra Chul, Memorial Bridge (Sta. C4), RID Samsen Office (Sta. C12) and RID Pakred Office (Sta. C22) along the estuary. The manner of gauging is assumed in such a way that the hourly water levels are recorded for every 24 hours until 9:00 a.m. and transmitted to the Bangkok Head Office within two days. The following boundary conditions are also to be provided to perform the flood prediction.

(1) Runoff discharges at Bang Sai which are predicted as the daily variables by the Basin Runoff Prediction Model and the Channel Routing Model and the Flood Plain Routing Model mentioned before; and

(2) Tidal levels in the Gulf of Thailand which are predicted as the hourly variables by the Harmonic Analysis.

In the premises of the aforesaid data collection, calibration and boundary conditions, the hourly water level is predicted through the Unsteady Flow Prediction Model for the optional points along the estuary of the Chao Phraya River.

5.4 Effectiveness of Flood Prediction

The effectiveness of flood prediction was examined through simulations using the hydrological gauging data recorded in 1978, 1980 and 1983 at the gauging stations to be selected for Step 1 Flood Forecasting System. The simulations were carried out subject to the 3 and 6-day advanced prediction. The 6-day prediction approximately corresponds to the short term prediction required of the Step 1 Flood Forecasting System. As the results of simulations, the effectiveness was evaluated as described hereinafter.

5.4.1 Accuracy of Daily Average Discharge Prediction in the Upper Reaches from Bang Sai

The flood discharge hydrographs are predicted for the prediction points of Nakhon Sawan, Chai Nat and Ang Thong where the observed discharge records are available. The prediction was made through the combination of the Basin Runoff Prediction Model, the Channel Routing Model and the Flood Plain Routing Model. The results of the prediction are as shown in Figs. 2-31 to 2-32 and Table 2-22. In this connection, the following evaluations are made.

(1) Prediction for Nakhon Sawan and Chai Nat

As shown in Table 2-22, the annual peak discharges are predicted 6 days in advance subject to the maximum difference of about 300 m3/s in comparison with the observed value. Considering that the difference of 300 m3/s in discharge is equivalent to a difference of about 15 cm in water level, the results of prediction is evaluated to be rather available. Further, the 3-day prediction will enable to improve the results of the 6-day prediction, especially the predicted discharges of more than 2,000 m3/s (refer to Table 2-22 and Figs. 2-31(1/3)-(2/3) and 2-32(1/3)-(2/3).

(2) Prediction for Ang Thong

The results of prediction is evaluated to be usable for the practical flood forecasting works as shown in Table 2-22 and Figs. 2-31(3/3) and 2-32(3/3). It is however noted that compared with the prediction results of Nakhon Sawan and Chai Nat, the errors of prediction are rather large. One of the causes of error is attributed to the reliability of discharges observed at Ang Thong where the period of field discharge measurement is quite limited. Accordingly, it is necessary to accumulate more sufficient data of field discharge measurement and further verify the effectiveness of the proposed flood prediction model.

5.4.2 Accuracy of Hourly Average Water Level Prediction for Tidal Compartment

The one-day maximum water levels were predicted through the Unsteady Flow Prediction Model for several points along the estuary and compared with the observed water level as shown in Table 2-23. In this prediction, the following premises are given:

(1) The data for prediction were set on the days when the annual maximum discharges were observed at Bang Sai in 1978, 1980 and 1983.

(2) The upstream boundary conditions were given from the daily average discharges predicted at Bang Sai either 3 days or 6 days in advance.

(3) The downstream boundary conditions were given from the hourly average tidal levels which are predicted through the Harmonic Analysis by using the preceding years tidal records of Fort Phra Chul (located about 1.0 km upstream from the river mouth).

The errors in the 6-day prediction ranges approximately from 10 cm to 30 cm and the maximum error of 30 cm occurred in the prediction for Sathu Pradit (located about 40 km upstream from the river mouth) on October 21, 1978 as shown in Table 2-23. However, in case of the 3-day prediction, the errors are reduced to mostly within 20 cm.

5.4.3 Expected Flood Lag Time

By integrating the observed and simulated flood traveling time (refer to Table 2-24), the following flood lag times are estimated to be possible for the respective flood prediction points.

(1) Nakhon Sawan

A term of about 8 days is estimated as the possible flood lag time which is governed by the flood in the Ping River Basin.

(2) Chai Nat, Sing Buri, Lop Buri and Ang Thong

A term of about 6 days is estimated as the possible flood lag time which is governed by the flood in the Sakae Krang River Basin.

(3) Ayutthaya

In the area along the downstream of Pasak River from the Rama VI Dam, a term of about 4 days is expected as the possible flood lag time which is governed by the flood in the Pasak River Basin. As for the area along the Chao Phraya River, the flood lag time of more than 10 days is expected due to the retarding effects in the upper reaches.

(4) Bangkok

In the same way as the prediction for Ayutthaya along the Chao Phraya River, the runoff discharge at Bang Sai can be predicted more than 10 days in advance. Further, the tidal prediction for the Gulf of Thailand can also be predicted through the Harmonic Analysis about one year in advance. Due to the said possible prediction, the water level for Bangkok can be predicted more than 10 days in advance.

5.4.4 Applicability of the Proposed System

As described in Subsections 5.4.1 and 5.4.2, a rather applicable accuracy of prediction results is expected in the proposed Step 1 Flood Forecasting System. It is also expected that the flood lag time at most prediction points will make it possible to secure the time for the short term prediction required for the Step 1 Flood Forecasting System. It is herein noted that the short term prediction time required for the Step 1 Flood Forecasting System is assumed to be almost equal to 5.5 days, the minimum value required under the present condition (refer to Sector 1 of Supporting Report, Planning Condition). It is, however, noted that the flood lag time at Ayutthaya is estimated at only about 4 days in case of a flood occurring in the Pasak River Basin which does not cover the required flood prediction time. Due to the above, one of the major objectives in the succeeding Step 2 Flood Forecasting System will be placed on the development of the measures for data collection and processing so as to shorten the above necessary flood prediction time.

6. Step 2 Hydrological Gauging System

As stated in Section 5, the Step 1 gauging system is formulated for the primary purpose of urgently providing the flood forecasting effects subject to the effective use of existing facilities. A certain improvement is, however, required in the accuracy of the available prediction time given by the Step 1 gauging system due to the limitation on number and coverage of existing hydrological gauging stations. The Step 2 gauging system is herein formulated to increase the accuracy of flood prediction results and protract the flood prediction time.